20th DOE/NRC NUCLEAR AIR CLEANING CONFERENCE

SESSION 4

REACTOR OPERATIONS

TUESDAY: August 23, 1988
CHAIRMEN: R.R. Weidler
C.A. Willis

OPENING COMMENTS OF SESSION CHAIRMAN WEIDLER

This session has been scheduled because of the extreme importance that operational problems have become for nuclear facilities. We find ourselves in the era when we are identifying, resolving, and upgrading systems, components, procedures, and training for the nuclear facilities that we designed several years ago.

At Duke Power for instance we find at least one HVAC or air cleaning problem on the "top 10" reliability concerns at each of our operating nuclear stations. Those problems must be addressed correctly and expeditiously. Typical problems we have, or are experiencing, are raw water fouled heat exchangers, unreliable damper operators, poor fan performance, and a multitude of I & C problems.

Eight papers will be presented this morning. These papers will present a typical and broad cross-section of operational HVAC and air cleaning problems facing the nuclear industry. One paper will discuss LERs related to HVAC and air cleaning. Two papers will discuss radioactive particle and gas migration and tracing techniques. Two papers will discuss containment cooling and temperature monitoring. One paper will discuss the strategy for monitoring exhaust stack emissions and one paper will discuss repairing a water damaged carbon adsorber. One paper will discuss upgrading a facility's radioactive air emission system. I believe we are just beginning to scratch the surface in the identification of these types of problems. In the future, we are going to need to apply additional resources to these areas, as well as the areas of systems and equipment, performance testing, cleaning techniques for raw water fouled systems, and equipment repair and replacement, and upgrading systems and equipment consistent with these "lessons learned."

REVIEW OF NUCLEAR AIR TREATMENT SYSTEM RELATED LICENSE EVENT REPORTS FOR THE PERIOD 1985 - 1987

John W. Jacox

President

JACOX ASSOCIATES

ABSTRACT

This paper will continue the review of HVAC/NATS related LERS presented at past Air Cleaning Conferences by Dr. D. W. Moeller and his associates. (1,2,3,4) The general approach and format are similar. LER abstracts from mid 1985 through 1987 were reviewed and those related to HVAC/NATS classified and analyzed. The categories were jointly developed by Dr. Moeller, Dr Casper Sun and myself. In appropriate cases both primary and secondary categories (codes) for a problem are given.

A basic listing by category and brief statistical review are presented. Additionally a number of categories are discussed in some detail. The categories chosen for specific review are intended to highlight particular problem areas. NUREG/CR-2000 "License Event Report (LER) Compilation" is the basis for the initial review and coding. (5) In essentially all cases where an LER is classified as of interest the complete LER was obtained and reviewed in full.

The intent of this paper is to provide a basis for the industry to document and analyze problem areas that require additional attention. It appears that about 15% of all LERS in the subject period are HVAC/NATS related. This figure is generally consistent with those (11-17% for PWRS and 20-29% for BWRS) reported at the 17th DOE Nuclear Air Cleaning Conference. It is hoped that such attention will allow additional resources to be allocated to upgrade systems, procedures and training as well as in some cases government regulation.

INTRODUCTION

The methodology used is straight forward. NUREG CR/2000 is a monthly USNRC publication listing all LERs with a brief abstract of each. This publication was reviewed from the October 1985 issue through the March 1988 issue. This covers a 30 month span which is the period of the review. Attention is called to the fact that due to the delay in the information becoming available to the NUREG editors the actual LERs lag the publication dates by a few, to as much as 9 months. The reason for this large spread is not specifically known but given the 30 month span of this review the data is valid, even with the delay and spread. The intent of this analysis is the over all problems highlighted by the LERs, not strictly the analysis of a particular limited period.

The initial coding of the LER was performed based on the NUREG abstracts. The basis for coding the Primary cause was the Root Cause as stated in the LER Abstract. If no specific declarative statement was found to define the Root Cause, the author determined it from reading the LER abstract. After the LERs of interest were determined in the NUREG, the actual full LERs were obtained and read in detail. In a very few cases the codes were revised after reading the full LER but this was an unusual occurrence. The NUREG/CR 2000 abstracts are sufficient to code the defined problem areas.

NUREG-1022, "License Event Report System - Description of Systems and Guidelines for Reporting" is recommended to those not familiar with LER reporting requirements. (6) On-line access to the LER data base for LERs starting 1-1-81 is available. Details can be found in NUREG/CR-3905. (7)

The 20 codes or categories used are a combination of historical precedent and the authors interest in some specific problem areas. These codes are listed in Table 1, "LER Failure Codes/Categories". These categories were additionally reviewed, modified and mutually agreed to by Drs. Moeller and Sun. It is of interest that some known problems were not reported as LERs. This will be discussed later in the paper. A statistical outline is presented in Tables 2 and 3. Discussion of significant problem areas, with some suggested approaches to reduce the continuing problems, are also presented.

There was one subjective aspect of this review that requires explanation. It was choosing the actual LERs to include in the review. Most are clear and unambiguous but a significant number can be open to different interpretations. These were in areas such as containment isolation, for example. Some events were clearly to be included since a NATS was directly involved. However, in others there was no direct NATS involvement so the event was not included. A leaking isolation valve is an example that was not included. Events involving radioactive gas release were included. These were included if a real release did occur or if a monitor indicated one in error. Since a great diversity of individuals submit LERs for the owners there is the probability that they may interpret the LER regulations and guidelines differently. They certainly phrase the description of a given event very differently. The detailed numbers of the total LERs and more importantly the individual codes should not be taken as anything more than the author's best judgement. There is no formal regulation or guideline for the type of coding performed here. This can account for some of the differences in the relative number of any given type of event in this paper compared with previous LER reviews. This paper also uses more categories than used in previous LER reviews.

A significant point in the assignment of codes when the LER did not specifically state a Root Cause is the possibility for differing codes to be validly applied. The most common problems were in the areas of Procedural Problems (PP) and Personnel Causes (PC). In all but a few cases either could be used as the Primary code with the other as the Secondary. Except for very limited cases where a Procedure was stated to be explicitly in error, the choice between blaming the error on a Procedural Problem or Personal Cause was extremely subjective. Incorrect calibration and design errors are also "Personnel Cause" but have been given separate categories to allow more detailed analysis.

As may be seen in Table 2, "Basic Tabulation of NATS LERs By Codes, Primary & Secondary", there are four significant codes that contain the majority of the primary problems. PC-16.9%, PP-10.9%, RM-26.2% and TD-12.6% for a total of 66.6% of all the subject LERs. For secondary causes again there were a few codes that covered the bulk of the problems but the distinction is not quite as extreme. This may be due to the less definitive nature of a secondary, or contributing, cause. Even with the somewhat more evenly distributed codes five clearly stand out as the major contributors. EC-9.8%, ME-11.5%, PC-14.2%, PP-15.8% and NS-21.2% for a total of 73.5%. These are the nine codes or causes of the LERs that are discussed. In a significant number of cases there are clear cause and effect relationships between the primary and secondary codes. Attention is called to the fact that even with the stated ambiguity of the PP and PC codes both are included in primary and secondary lists of major causes so the assignment of an LER to one or the other is not of critical significance for the purposes of this paper.

DISCUSSION

The first comparison is that of BWR vs. PWR plants. This data is given in Table 3. For the period studied the result is somewhat different than in earlier papers. This period gives 46.4% for BWRs and 53.6% for PWRs. The current LERs are in the reverse ratio of those found in previous studies. A possible cause could be that a number of older BWR plants had been shut down for most of this period. For example, the three Browns Ferry Plants and the two Peach Bottom plants were in cold shut down. Some LERs were issued for these plants but one would expect that there are fewer when a plant is in cold shut down than in full operation. This is simply a possibility for consideration. No data has been reviewed (if indeed such data has been tabulated) to analyze the reason for this difference.

PRIMARY CAUSES

The largest primary code is RM or radiation monitor caused. It is the largest by a factor of nearly two. This code includes only HVAC/NATS and stack monitor LERs plus others that caused the start of a NATS system. It does not include any liquid, reactor or other radiation monitor LERs.

The largest single cause of a false radiation monitor alarm, or actuation of some other system, is from electrical noise (spikes and RF) on the signal line connecting the remote sensor to the control room. Of the Radiation Monitor LERs 123 were directly attributed to Noise Spikes as the Root Cause. This is 35% of all the RM LERs. Additionally many were listed with the Root Cause as unknown. It is highly probable that most of these were also caused by signal line noise.

Given the large number of these occurrences the author contacted a number of plants, NRC personnel and radiation monitor vendors to obtain information on the various points of view regarding this problem. Based on an early inquiry a member of a government body made a similar independent (informal) survey and obtained exactly the same responses as the author. In fact, a memo covering his investigation contained some of the exact same responses and phrasing as those received by the author. For obvious reasons these personnel would discuss the situation only "off the record" and with assurances that no personal or location names would be used that could identify the source. This is unfortunate but certainly understandable. The promise of anonymity was universally required by all personnel contacted in the preparation of this paper. All agreed that there is no valid technical reason that this well known problem could not be solved with existing, or very short term development, technology. Some plant personnel stated that the problem had been solved with the addition of a simple R/C electrical filtering or smoothing circuit obtained from the radiation monitor vendor. This is hardly credible since there were continuing radiation monitor LERs from the specific plants in question. Further, these same plants continued to assign electrical noise spikes as the Root Cause for this problem in the LERs submitted. The reasons for these inconsistencies may only be speculated. What ever the reasons, it is clear that the installation of a "simple, cheap R/C filter" has not solved the problem. The number of radiation monitor caused LERs has continued unabated long past the period the filters were related to have been installed. This indicates the need for some more positive method of reducing the problem of signal line noise spikes.

Current digital technology offers at least two major approaches. The first is to convert from an analog to a digital signal at the actual sensor so the signal line will transmit a digital signal not as easily confused by electrical spikes. This option is currently offered by radiation monitor vendors. It is, however, an expensive solution since it requires replacing most of the existing system.

A second solution for area radiation monitors, and most other NATS related radiation monitors, is to use a commercially available, industrial microprocessor based, controller in line with the signal path. It will compare the incoming signal waveform with a set of waveform parameters held in the controllers memory. The theory behind this is that the physically possible waveforms (that is, raise time, duration, level, decay time, etc. of a radiation field) can be well defined for a given sensor location. Simply stated, there is no credible source of very short radiation spikes of micro or milli second duration to these sensors. Even in the worst possible case of a major criticality excursion the fast rise time could not be followed by a millisecond decay in power plants. A "slug" or bubble of contaminated air or gas in a duct or stack could cause a short duration increase in radiation as it passed the sensor. If such an event took place, and it were only of a few milliseconds duration, the event would be over far faster than any mechanical response time for the system to react. The most likely interpretation of such an event would be that it was a spurious alarm unless there was other concurrent corroborating data. This approach would allow a microprocessor based controller to read the signal real time, less some fraction of a second, and pass only "real" signals. Such a device would have a "watchdog relay" to let the signal return to its original unprocessed path if the controllers built in self diagnostics found any fault within itself. This controller would be in the control room immediately before the existing control system so it would not require extensive environmental qualification. This device is in industrial use in very nearly the configuration required for use in the nuclear industry. Its use could greatly reduce this source of false radiation signals and alarms.

The informal response of those contacted at utilities was that this controller would very likely solve the problem, but it was probably more trouble to introduce such a "new" device with all the attendant paper work than to simply live with the problem as it currently exists. The procedural aspects of the modification clearly were of more concern in these informal discussions than the technology or hardware. It will be interesting to see if the problem of false radiation monitor caused LERs is any different at the 21st conference in two more years.

The second and third most common primary causes are PP and PC. These are very closely related. In only rare instances were the Procedures actually stated to be in error. The more common remarks were that the Procedures were incomplete or ambiguous. This leads us into the ongoing philosophical debate in the industry of extremely detailed Procedures vs. highly trained personnel. Obviously the Procedure should not be in conflict with the concept of trained personnel but this is almost the basis of the debate. On one hand a Procedure must contain all the basic steps required, and be a clear statement of the objective of the work. Equally it is absolutely impossible, even in theory, to write a Procedure that will cover ALL possible contingencies. This is where the trained, experienced technician or engineer must be trusted to at least recognize that something not covered in the Procedure has been encountered.

Many of us in the nuclear air cleaning community are aware of the decade long, often heated, debate on the desirability of a personnel qualification standard for ANSI/ASME N510 testing. (8) The final decision was that no such standard was required. This decision was justified partly on the basis of very detailed Procedures. In reading the actual LERs it was often not at all clear where a Procedural problem ended and lack of good training and/or experienced personnel began. Obviously on any given question reasonable engineers may disagree. The point to be made is that BOTH the Procedures and the personnel must meet higher minimum standards based on the large number of repeat LERs caused by these inseparable problems.

One suggested approach is to openly recognize that no Procedure can predict all contingencies and rely to a greater extent on well trained, experienced personnel to implement the Procedure, and their direct feedback to improve it.

Toxic gas detectors are the final major primary cause of these LERs. Again the problem has been long known from these conferences and industry discussions. The instruments commonly used in nuclear power plants are very out of date compared to those used in other industries. The basis for this statement is review of contemporary detector literature and personal discussion with a number of the major TGD vendors technical personnel. The vendors are easily identified as they are specifically noted on the LERs. Without exception the vendors stated that they had far more reliable instruments available today but could not offer them to the utilities for nuclear use since they were not "nuclear qualified". Further the vendors stated they had no economic incentive to invest the hundreds of thousands of dollars required to so qualify the instruments for such a small market. One senior product line manager stated he was embarrassed to provide such out of date equipment. He further stated his only real economic alternative would be to completely stop supporting the industry for this type of instrument. At least the vendors have, to date, continued to support the installed instruments with consumables and service. It is doubtful this can continue for the next 40 years of projected plant life.

Additional Toxic Gas Detector LER information is presented in Appendix A. This data is from a sample of control room TGD LERs for the period 6, November 1979 through 29, April 1987. It is a completely separate listing and partially overlaps the main LER listing. While the time period is longer than the main LER review it is for a much smaller number of reactors. Only 25 reactors were included in this particular study. This data is presented to highlight the common and repeat nature of most problems. They are often mundane but still serious enough to require technicai and physical attention as well as the submission of an LER.

SECONDARY CAUSES

The secondary causes are in two cases the same as the primary. Personnel Causes and Procedural Problems. The same discussion as for primary causes is directly applicable. The continuing effort to write ever more detailed Procedures is clearly less than completely successful. These PP and PC LERs are strong evidence of the impossibility of predicting every possible contingency. Including the previously mentioned additional categories such as calibration error and design error add even a greater percentage of causes to the personnel area.

The largest single secondary cause is electrical noise on signal lines. This includes not only signal lines to radiation monitors but essentially all remote sensors of all types. The discussion for secondary causes is again the same as for a primary cause.

The two new categories are EC, electrical component failure, and ME, mechanical component failure. These include all components from a blown fuse with no assignable cause, and therefore blaming the fuse by default, to a broken linkage for a motor operated damper. The scope of these failures is too broad to allow a detailed analysis within this paper. The range of components that failed is quite wide and there are no obvious major weak points. This is particularly true since this paper only covers NATS so problem components in other systems are not included.

The next most significant secondary cause is DE, design or installation error at 9.8%. This type of error is totally correctable, at least in theory. If we take both primary and secondary DE causes the total number is 157. As has been mentioned, this is really another type of "Personnel Cause" problem.

GENERAL COMMENTS

One of the areas of NATS problems that was of particular interest to the author during this investigation was that of fire protection water being released into the carbon adsorbent. It was very surprising to find how very few LERs, 5, were submitted on this problem. Since the author has first hand knowledge of a number of such events that were not submitted as LERs additional investigation was undertaken to determine why. The answer seems to be at least partly in the rules and guidelines for LER submission. In a number of instances where water was known to have leaked, or been unintentionally released, into an NATS this occurred before an Operating License was issued. This fact relieved the Owner of the requirement of submitting an LER. This is not to say that LERs may not be required before an Operating License has been issued. Simply that these particular occurrences were not required to be reportable. In at least three unreported cases known to have occurred there was actual damage to the physical system that required repair and/or the fire protection system was modified to reduce the probability of a reoccurrence. Since there was no formal report of these problems it is more difficult for others to learn from these instances. Fortunately one of these events is covered by a paper being presented later in this session by Mr. Pete Olsen (Paper 4-7). It is not suggested that LERs are the reporting method of choice, only that such information does need timely distribution.

It is interesting that there were no LERs submitted that listed HEPA filter problems as the cause. Since a number of cases where N510 testing proved the HEPA filter banks either failed the leakage requirements or exceeded the pressure drop requirements are known to the author it is obvious that an LER review will not provide all the detailed data an NATS specialist would desire.

There were no events that attributed the Root Cause to improper or insufficient training in performing the N510 Acceptance or Operational testing. Some were expected by the author, but that none were found is certainly partly attributable to the same points discussed for the Procedural Problems and Personnel Cause. When is lack of adequate training or experience a "Personnel Cause"?

While not originally planned to be in the scope of this paper the compressed air systems in a power plant have direct impact on and interrelationship with the NATS. A few LERs did report that the compressed air supply was a cause but these are in the "Unknown or Other" category. An excellent current reference is NUREG-1275, Volume 2, "Operating Experience Feedback Report - Air Systems Problems". (9)

Continuing review of NUREG/CR-2000 since the March 1988 issue indicates no changes in number or type of NATS LERs. This is through the June 1988 issue.

CONCLUSION

There are a number of observations and recommendations that may be drawn from the LERs included in this review. The first is that there seems to be no significant difference in the total number per year or general distribution of NATS related LERs in this most recent period of study compared to the previous studies.

The number of events attributable to human error is also generally similar to past studies. This comparison is complicated by the complex interplay of Procedural Problems with Personnel Cause discussed, as well as slightly different categories being used.

The position that all Procedural problems are in fact personnel problems may be made from two points of view. First the Procedures are written and extensively reviewed by employees so by definition if they are in error it is a Personnel Cause. This is not offered simply as an overly broad generalization or syllogism that all problems involve some human failure. It is made to reinforce the idea that all Procedures require USER understanding, knowledge and feedback if they are to be as technically correct and reasonable to use as possible.

The second aspect of personnel failings that could change a Procedural Problem to a Personnel Cause is the area of user training and experience. Even if a Procedure is in substantial error the user should be expert enough in the subject system and technology to recognize the error, and stop before any actual physical problem occurs. In this interpretation the only reportable event would be if a Technical Specification schedule were missed due to the delay caused by such a situation when the problem was recognized by the user and work stopped.

Unfortunately the comments and recommendations made in the previous reviews, references 1, 2, 3, and 4, all still apply. Note that reference 4 is from the 13th conference held in 1974. The data in this current study wholly support that the earlier comments are still all too valid. Essentially the same problems, or at least the same types of problems, are being repeated in both new and older plants. This would seem to support the position that additional in-depth training can be a major aspect of the answer to our continuing problems.

Along with training, experience is also necessary. Given that a perfectly complete Procedure is impossible so is a perfectly complete training program. Clearly we must do much better in using the expertise of those who have actual in-depth knowledge and experience to pass on to others entering the NATS field. This technology transfer will undoubtedly take many forms; in-house formal training, on the job training,and formal outside classes and workshops. Better use of consultants and contractors must be made by using them to train rather than simply performing work then leaving. This training may be formal, on the job as they work or both. Reducing repeated problems is far too important to our industry to allow any useful method to remain untapped.

Even the type of training is subject to differing opinions. Should it be very narrow in scope so the user is totally familiar with the subject Procedure to at least the partial exclusion of the rest of the plant or should it be a broader orientation with basic principals stressed. Unfortunately there is no one single "correct" answer. This philosophical problem has been debated by education professionals for centuries. Whatever the "best" answer is it should clearly include better communication with the working level plant personnel.

At many plants the "hands on" engineers and technicians do not regularly see the actual LERs or much of the other vast amount of information from the NRC and owners available somewhere on-site. Certainly each individual should not receive their own copy of each item or we would be crushed by the paper. Selectivity is necessary.

There must, however, be some way to get this very valuable information to the working level personnel and not limit it to Licensing or management as often happens today. Equally the working level engineers and technicians can provide feedback from their hands on work that will assist not only their own plant but the rest of the industry. A great deal of effort has been put into industry and "users group" data bases. Perhaps something as simple as adding additional terminals so that each engineer could directly check on his area of responsibility for relevant input from these various on-line data bases, including LERs, would be helpful.

There are a large number of reportable events that are at least partially the result of the extreme procedural requirements and paper work necessary to upgrade equipment (Radiation Monitors and Toxic Gas Detectors totaling 38.8%). Some way to revise both regulations and plant Procedures to allow the state of the art equipment to be used to upgrade the plant, and, therefore, reduce these continuing problems is extremely desirable. Clearly great care must be taken to ensure that any change provides configuration control as well as meeting all minimum technical and legal requirements. This is a major problem in the nuclear industry in the United States and will certainly not be solved here. As shown in these LER reviews the same problems have continued for decades. Not making technical improvements because the paperwork required is too difficult and expensive is not an acceptable situation.

A figure that is often offered for the average cost to a utility to carry out the work required to recognize, investigate and submit an LER is $10,000.00. This figure multiplied by the 1,346 NATS LER gives an overall cost of $1,346,000.00 for NATS related LERs ($93,250,000.00 for all the LERs) in this period. These are not huge numbers but most of the problems are unnecessary if we reasonably assume repeat problems are generally correctable. The concept that the total cost of LERs be assigned to the cost of the plant system that caused them is offered for consideration. This would allow more accurate cost benefit analysis of proposed changes.

It is hoped and suggested that a similar study will be made for the period starting at the end of that covered in this paper until the next conference. This type of review should be a ongoing project for our industry speciality.

ACKNOWLEDGMENT

I am pleased to acknowledge most generous assistance from Dr. D. W. Moeller of Harvard University, Dr. Casper Sun of Brookhaven National Laboratory and J. W. Driscoll of Argonne National Laboratory - West. Without their help this paper would not have been possible.

REFERENCES

1. "Commentary In Nuclear Power Plant Control Room Habitability - Including A Review Of Related LERs (1981 - 1983), Moeller, D. W., Kotra, J. P., ACRS/USNRC, 18th NACC, CONF-840806, 1984

2. "Failures In Air-Cleaning, Air Monitoring and Ventilation Systems In Commercial Nuclear Power Plants (1978 - 1981)", Moeller, D. W., Sun, L. S. C., ACRS/USNRC, 17th NACC, CONF-820833, 1982

3. "Review Of Failures In Nuclear Air Cleaning Systems", Moeller, D. W., ACRS/USNRC, 15th NACC, CONF-780819, 1978

4. "Performance of Air Cleaning Systems In Nuclear Facilities", Moeller, D. W., ACRS/USNRC, 13th NACC, CONF-740807, 1974

5. "License Event Report (LER) Compilation", NUREG/CR-2000, Monthly, USNRC, Washington, DC

6. "License Event Report System - Description of Systems and Guidelines for Reporting", NUREG-1022, USNRC, Washington, DC

7. "Sequence Coding and Search System for Licensee Event Reports", NUREG/CR-3905 (Four Volumes), USNRC, Washington, DC

8. "Testing of Nuclear Air-Cleaning Systems, ANSI/ ASME N510-1980, ASME, 355 East 47th Street, New York, NY 10017

9. "Operating Experience Feedback Report - Air Systems Problems", NUREG-1275 Volume 2, USNRC, Washington, DC

TABLE 1

LER FAILURE CATEGORIES (PRIMARY & SECONDARY)	CODES
1. Adsorber problems other than CW or CP	AP
2. Carbon Bed Packing/Settling Problems	CP
3. Carbon Wetting	CW
4. Design or Installation Errors	DE
5. Electrical Component Failure	EC
6. HEPA Filter Problems	HF
7. Test or Technical Specification Violations	TS
8. Mechanical Component Failure	ME
9. Personnel Cause	PC
10. Procedure Problems	PP
11. Radiation Monitor Problems	RM
12. Toxic Gas Detector Problems	TD
13. Ventilation and Isolation Integrality Problems	VA
14. Weather and Lighting (Mother Nature)	MN
15. Electrical Noise and Spikes	NS
16. Ageing, Dust and Dirt Buildup	AD
17. Fire Protection System and Smoke Problems	FS
18. Instrumentation Setpoint Drift and Wrong Setting	SP
19. Radioactive Gaseous Release and Shine	RG
20. Unknown and Other	UK

TABLE 2

BASIC TABULATION OF NATS LERs BY CODES, PRIMARY & SECONDARY

	CODE	PRIMARY NUMBER	CAUSE PERCENT	SECONDARY NUMBER	CAUSE PERCENT
1.	AP	7	0.5	14	2.1
2.	CP	2	0.2	1	0.2
3.	CW	5	0.4	1	0.2
4.	DE	102	7.6	40	6.3
5.	EC	95	7.1	62	9.8
6.	HF	0	0.0	0	0.0
7.	TS	36	2.7	22	3.5
8.	ME	61	4.5	73	11.5
9.	PC	227	16.9	90	14.2
10.	PP	146	10.9	100	15.8
11.	RM	353	26.2	29	4.6
12.	TD	170	12.6	7	1.1
13.	VA	8	0.6	1	0.2
14.	MN	11	0.8	2	0.3
15.	NS	20	1.5	134	21.2
16.	AD	10	0.7	4	0.6
17.	FS	19	1.4	9	1.4
18.	SP	12	0.9	12	1.9
19.	RG	15	1.1	5	0.8
20.	UK	47	3.5	27	4.3
TOTALS		1346	100.0	633	100.0

The total number of LERs in the subject period was 9325.

TABLE 3

LERs BY ACTUAL DATE OF OCCURRENCE AND REACTOR TYPE

YEAR	REACTOR TYPE BWR	PWR	TOTAL/YEAR
1980	1	1	2
1981	0	0	0
1982	1	2	3
1983	3	8	11
1984	7	12	19
1985	102	121	223
1986	265	254	520
1987	243	321	564
1988	1	1	2
Totals	624	720	1344

1. Two HTGR LERs were found and are not shown above. This brings the grand total to 1346.

2. For the purposes of this paper an LER revision was treated as an independent LER so some of the older LER dates are actually the original event date and the LER found in the current period a revision based on the original event date. The fact that an LER item can be open for such extended periods is considered significant and can be an interesting subject for a future study.

3. The percent of LERs for BWR plants is 46.4%.

4. The percent of LERs for PWR plants is 53.6%.

5. No percentage was calculated for the 2 HTGR LERs.

APPENDIX A

TOXIC GAS DETECTOR CONTROL ROOM RELATED LERs 11/79 through 4/87

LER CAUSE CODE	NUMBER LERs	PROBLEM TYPE DESCRIPTION
PAPER	39	PAPER TAPE/TAPE DRIVE PROBLEMS
ENVIRON	31	ENVIRONMENTAL PROBLEMS
OTHER	11	ALL PROBLEMS NOT OTHERWISE LISTED
UNKNOWN	26	ROOT CAUSE IS UNKNOWN
ELECTRIC	22	ELECTRICAL CIRCUIT PROBLEMS
POWER	14	LOSS OF POWER TO THE TGD
ELEC LYT	36	ELECTROLYTE RELATED PROBLEMS
MECH	14	MECHANICAL FAILURES
OPTICS	16	OPTICAL SYSTEM PROBLEMS
MAINT	31	MAINTENANCE CAUSED PROBLEMS
Total LERs	240	

1. The importance of the data in APPENDIX A is the extreme repeatability of the problems.

2. The docket numbers define a specific reactor, not site. That is, if there is more than one reactor at a given site there will be separate docket numbers for each reactor.

3. The total number of reactors in this study is 25.

APPENDIX A1

PAPER TAPE SYSTEM PROBLEMS

DOCKET	LER	DESCRIPTION
263	84-004	Ran out of tape in cassette
263	85-005	Misaligned tape drive magnets
263	85-016	Broken detector tape
263	85-017	Broken tape; caught on detector head
263	85-020	Broken tape due to tape speed surge
263	85-021	Tape break due to bad tapes
263	86-004	Tape break
348	81-046	Sheared pin in paper drive
348	82-023	Faulty gear in paper drive motor
348	82-023	Improper tape loading
348	82-030	Sheared pin in paper drive
348	82-030	Faulty paper drive motor
348	82-033	Sheared pin in paper drive
348	82-035	Faulty paper drive motor
348	82-040	Sheared pin in paper drive
348	82-050	Sheared pin due to wrong size reels
348	82-055	Faulty paper drive motor
348	83-003	Faulty gear in paper drive motor
348	83-050	Broken tape; cause unknown
348	83-063	Broken tape; cause unknown
348	83-073	Faulty tape mounting shaft broke tape
348	83-077	Interfering motion indicator broke tape
364	81-052	Paper scrap jammed in drive
364	82-001	Tape ran out
364	82-014	Sheared pin; motion indicator bound tape
373	82-046	Improper loading of tape
373	82-060	Broken tape
373	82-157	Broken tape
397	84-019	Jammed paper tape cassette
461	86-003	Factory over tension broke tape
461	87-010	Discolored tape; improper reloading
461	87-011	Discolored tape
461	87-012	Tape ran out
482	85-052	Broken tape
482	85-056	Discolored tape
482	85-058	Tape bunches up
482	85-061	Broken tape
482	85-081	Broken tape
482	86-002	Broken tape

APPENDIX A2

ELECTROLYTE RELATED PROBLEMS

DOCKET	LER	DESCRIPTION
325	84-032	Clogged orifice & wick
325	85-006	Fungi growth in orifices
327	80-163	Clogged filter & capillary tubes
327	81-022	Clogged filter & orifices
334	80-090	Clogged wicks & orifices
334	80-107	Clogged wicks & orifices; induced vacuum
334	80-115	Clogged wicks & orifices
334	80-118	Clogged wicks & orifices; induced vacuum
334	81-005	Clogged wicks & orifices
334	81-007	Clogged wicks & orifices
334	81-011	Slow electrolyte drip
334	81-012	Slow electrolyte drip
334	81-022	Clogged wicks & orifices
334	81-035	Clogged wicks & orifices
334	81-039	Clogged wicks & orifices
334	81-050	Clogged orifices
334	81-005	Clogged orifices
334	81-073	Clogged orifices
334	82-028	Clogged wicks & reservoir
334	82-029	Clogged wicks, orifices & filters
334	82-041	Clogged orifices
335	81-028	Clogged wick
336	81-012	Clogged filters
346	81-018	Detector was clogged
346	83-013	Clogged orifice allowed wick to dry
373	85-063	Clogged orifices
373	85-067	Change in electrolyte drip rate
387	82-025	Lack of electrolyte
387	82-053	Clogged wick
387	83-008	Contaminated wicks
387	83-020	Crystallized electrolyte; wick & orifice
387	83-040	Wrong electrolyte solution
387	83-110	Impurities in electrolyte clogged wick
387	83-135	Clogged wicks
387	83-158	Clogged wicks & orifices
416	82-064	Clogged internal flow paths

APPENDIX A3

ENVIRONMENTAL PROBLEMS

DOCKET	LER	DESCRIPTION
271	85-012	Halon R-22 from A/C in intake
325	82-005	Corrosion of detector armature
325	84-036	Minute chlorine leaks
325	85-013	Open isolation valve on tank car
334	81-027	Dirty wicks from dust
341	86-024	Radio-frequency interference
344	81-020	Dirty bearings in reagent metering pump
352	85-044	Halon present in vent system
352	86-043	Undercompensation for humidity & CO2
352	86-046	Rain water on probes
352	87-003	Snow on probes
352	87-009	Condensate dripping on probe
361	84-032	Various environmental causes
361	84-037	Various environmental causes
361	84-042	Various environmental causes
361	84-052	Various environmental causes
361	84-055	Various environmental causes
361	84-065	Various environmental causes
361	85-003	Various environmental causes
361	85-010	Various environmental causes
361	85-019	Various environmental causes
361	85-029	Various environmental causes
373	82-145	Dirty chlorine concentration lens
373	84-017	Snow buildup froze detector
373	85-044	Radio-frequency interference
373	85-062	Radio-frequency interference
382	86-003	Nitrous oxide in air; overly sensitive
387	83-008	Contaminated wicks
397	84-102	Temperature sensitive board; set point drift
416	87-002	Radio-frequency interference
424	87-019	Oversensitive to nitrogen dioxide

APPENDIX A4

MAINTENANCE PROBLEMS

DOCKET	LER	DESCRIPTION
321	85-037	Accidental trip during maintenance
325	82-090	18 month check overdue; computer error
327	80-119	Set point drift
327	85-033	Improper maintenance procedure
346	82-015	Maintenance procedure misunderstood
346	82-065	Maintenance procedure misunderstood
352	84-017	Improper initial set point
352	85-065	Recalibration
352	86-044	Set point too high; recalibrated
361	82-052	set point drift
361	82-054	set point drift
361	82-055	set point drift
361	82-058	set point drift
361	83-023	set point drift
361	83-047	Wrong alarm set point
361	84-006	Set point at threshold level
361	84-012	Conservative alarm set points
361	84-021	Conservative alarm set points
361	84-026	Conservative alarm set points
366	81-018	Improper testing procedures
373	85-039	Out of calibration
373	85-065	Set point drift
382	85-002	Trip during recalibration
397	84-066	Improper maintenance procedure
397	84-102	Undercompensation for temperature in calibration
416	83-046	Overdue surveillance; personnel error
416	83-092	Improper maintenance procedures
416	83-147	Sub-grade parts installed for maintenance
416	84-003	Bad maintenance procedure; power loss
423	86-031	Improper maintenance caused probe to dry
461	87-002	Technician removed optics lamp

APPENDIX A5

ELECTRICAL SYSTEM PROBLEMS

DOCKET	LER	DESCRIPTION
320	82-021	Burned out bulb in meter relay assembly
320	84-022	Disconnected lead to electrolyte sensor
325	86-003	Defective circuit board
335	81-012	Loose connection on reset button
346	81-018	Blown circuit board
348	81-046	Faulty bulb
348	83-062	Faulty zero potentiometer
352	85-094	Bad servo mechanism
352	86-022	Servo mechanism problem
352	87-008	Probe malfunction
361	83-101	Bad connection on actuation circuitry
361	83-115	Amplifier gain incorrect
361	83-139	Defective silicon control rectifier
361	86-034	Jumper wire dislodged by technician
364	81-017	Broken reset switch
373	83-051	Loose ground wire on circuit board
373	83-077	Bad master fault bulb
387	83-075	Requires manual reset after power outage
397	84-073	Loose connection on zero potentiometer
397	84-102	Set point drift;temperature sensitive board
397	84-109	Current surge form replacing bulb
482	85-011	Bad lamps

APPENDIX A6

POWER/POWER LOSS PROBLEMS

DOCKET	LER	DESCRIPTION
325	84-016	Loss of power
346	81-013	Added heat tracing blew 10 amp fuse
352	84-006	Loss of power
352	84-020	Loss of power
352	85-076	Loss of power
361	83-047	Discharged battery supply
362	87-008	Loss of power
373	85-060	Loss of power
387	83-075	Loss of power; requires manual reset
416	84-001	Loss of power
416	84-003	Loss of power; bad maintenance
482	86-001	Blown fuse due to sample pump failure
482	86-015	Pinched wire in sample fan
482	86-062	Loss of power

APPENDIX A7

OPTICAL SYSTEM PROBLEMS

DOCKET	LER	DESCRIPTION
263	85-011	Failed optics lamp
263	85-016	Debris in optical detector
263	82-022	Faulty optics lamp holder
320	82-022	Failed optiacl transister
348	80-032	Plastic stuck in optical detector
348	82-025	Faulty photocell light bulb
348	82-055	Fauilty light difussion disk
348	83-025	Broken wire in fiber optics
348	83-052	Failure of optic lamp bulb
361	83-006	Bad sample cell
373	82-145	Dirty chlorune concentration lens
373	84-017	Fauilty optical isolator
397	84-107	Loose optics indicating lamp
482	85-062	Burned out lamp in analyzer circuit
482	86-071	Bad bulb

APPENDIX A8

MECHANICAL PROBLEMS

DOCKET	LER	DESCRIPTION
320	82-017	Leak in sample flow path at the intake filter
321	80-091	Open winding on sample fan motor
321	80-106	Dry lubrication wicks for sample fan bearings
325	85-021	Electrolyte level indicator stuck
334	81-050	Improper reservoir venting
334	81-052	Improper reservoir venting
334	83-013	Electrolyte level indicator stuck
344	81-020	Dirty bearings in reagent metering pump
346	81-058	Sample discharge pressure GT intake
348	80-032	Cracked pump diaphragm
352	85-094	Bad servo mechanism gave bad wave length
352	86-022	Bad servo mechanism
461	87-003	Broken edge connector pin
482	86-001	Failure of sample pump

APPENDIX A9

OTHER PROBLEMS

DOCKET	LER	DESCRIPTION
324	82-024	Design logic problem; system control switch
324	82-084	Design problem, CR isolation dampers don't close
334	87-010	Excessive in-leakage into sample duct
346	83-031	Detectors not protected from missiles
348	82-063	Faulty solenoid on isolation valve
348	83-087	Faulty solenoid on isolation valve
352	85-101	Nitrogen zeroing gas ran out
382	84-001	Resetting caused high radiation spike
387	82-073	Too much heat tracing dried up drip leg
387	83-040	Misplacement of heat tracing temperature sensor
416	86-013	Improper sample flow

APPENDIX A10

UNKNOWN CAUSES

DOCKET	LER	DESCRIPTION
263	84-031	Spurious
321	85-033	Spurious
325	79-095	Cause unknown
325	85-002	Spurious
325	85-015	Cause unknown
325	85-024	Spurious
325	85-057	Spurious
325	85-064	Spurious
327	86-021	Cause unknown
335	82-003	Cause unknown
346	82-065	Chlorine detector malfunction
352	85-090	Cause unknown
361	82-005	Spurious actuation
361	82-099	Spurious actuation
361	85-052	Spurious
397	86-007	Cause unknown
397	86-034	Cause unknown
397	86-035	Cause unknown
397	86-041	Cause unknown
397	86-043	Cause unknown
416	85-044	Cause unknown
416	85-047	Cause unknown
482	85-033	Guess; electrical spike
482	86-063	Guess; electrical spike
482	87-008	Guess; electrical spike
482	87-012	Guess; electrical spike

DISCUSSION

MOELLER: This is a comment, not a question. Your data show that the total number of LERs being reported by licensees operating BWRs and PWRs are about the same. Since there are roughly twice as many PWRs in operation in the U.S. as there are BWRs, this means that the number of LERs being reported per plant per year for BWRs is about double that for PWRs.

JACOX: Dr. Moeller, I agree and thank you for pointing this out. However, even when compared to the overall raw number of LERs in past papers there does appear to be a possible change in the ratio of PWR vs BWR licensee event reports. I did not look at the number of licensee event reports per plant but only on a total per type basis.

FRECHETTE: You implied that the main reluctance of a utility to make plant changes is paper work avoidance. In reality, too, the reluctance is cost avoidance that must be passed on to the customer. Today, with the "paper" requirements, configuration control, engineering costs, etc., one can hardly change even the smallest plant component without expending a minimum of tens of thousands of dollars. Is this not the reason for the resistance to plant changes?

JACOX: I think we are saying the same thing in slightly different terms. Certainly, it is the cost of the paper work that I refer to. However, I still have two problems with what seems to be a general industry attitude. First, the actual cost of the recommended physical or technical improvement is not formally compared to the cost of the "paperwork" for either short or long term cost benefit. Second, the cost of either or both of these options is often not known as no specific data have been kept to allow such a specific analysis.

A THREE-PART STRATEGY FOR CONTINUOUS EXTRACTIVE MONITORING OF HAZARDOUS PARTICULATE EMISSIONS FROM EXHAUST STACKS

Alfred C. Schmidt MS, PE
Schmidt Instrument Co., San Carlos, California

ABSTRACT

Because of transmission losses, the customary isokinetic sampling procedures that are used for short interval aerosol sampling are not appropriate for continuous extractive monitoring of hazardous particulate emissions from exhaust stacks. A three-part strategy is described in this paper in which (1) the importance of particle size is recognized in relation to probe transmission and to the performance that is needed; (2) the sample is extracted where it will include all particle sizes that are present; and (3) transmission and entry losses are minimized by employing the latest advances in probe design and operation. Some of the points that are emphasized include: the need for specifying monitoring system performance as a function of particle size; the need for quantitative performance testing; and the need for keeping the flow in a monitoring probe constant at "the flow of best transmission," and using other means, such as flow substitution, for matching the stack velocity.

INTRODUCTION

There are two main reasons for extractive monitoring of hazardous particulate emissions: (1) because in-situ monitoring methods, such as light scattering, cannot distinguish between hazardous and harmless particles, and (2) because in-situ monitoring methods look at too small a volume to detect concentrations in the microgram per cubic meter, or microcurie per cubic meter ranges that are important for many hazardous substances. Extractive monitoring gets around those limitations by concentrating the particles from many cubic meters of air onto a small filter surface where they can be counted for radioactivity, or analyzed by a number of chemical or physical methods.

Although continuous extractive particulate monitoring [CEPM] presents some challenging problems, it has been employed for many years at nuclear facilities, using radiation detectors which are pointed at the filter surface to provide real time measurements of airborne radioactivity. Consequently, there is a wealth of experience to draw on in applying it to other applications. Some of the hazardous substances which call for this kind of monitoring include[1]:

Arsenic	Nickel
Beryllium	Silver
Cadmium	Uranium
Chromium	Radioactive substances
Cobalt	Carcinogenic substances
Copper	Mutagenic substances
Lead	Potent pharmaceuticals
Mercury	Biologically active substances

Continuous extractive particulate monitoring [CEPM] differs from periodic testing in that it provides a continuous record of the particulate emissions from exhaust stacks which can be used to prove compliance with emission standards and to quiet the public's fears about potential dangers. When combined with real time analysis of the sample it can serve to alert plant operators that a hazardous condition exists and to actuate automatic containment measures. All of this requires that the monitoring equipment is properly designed and is kept in good operating condition. This in turn requires management commitment to the monitoring program so that it is not forgotten in the press of other business [2,3,4].

Most of the development work to date on CEPM has dealt with isolated parts of the problem:

- Some designers have built elaborate multiple nozzle arrays to sample simultaneously from all parts of the stack, without considering the effect of the small inlet nozzles and tubing bends on keeping the larger particles from reaching the collection filter.
- Other designers have put great emphasis on keeping the nozzles precisely isokinetic, without considering the effect of changing flow rates on transmission losses.
- Frequently designers have sought ideal sampling conditions near the top of a stack, only to lose most of the sample by piping it long distances to a collection filter and analyzer located near the base.

Perhaps the biggest obstacle to better development has been the lack of quantitative performance standards, based on particle size, which would force designers to test and improve their products.

In place of this piecemeal approach there is a need for a comprehensive strategy that simultaneously considers the three basic parts of the problem:

1. The importance of particle size;
2. Where to extract the sample;
3. How to minimize transmission and entry losses.

Hopefully this paper will supply the reader with enough information to write a meaningful performance specification, and enough understanding of the difficulties to recognize that a high level of professional competence is required to solve them. For simplicity, graphical rather than mathematical presentations have been used wherever possible. Also for simplicity, it has been assumed that the particles are chemically stable and are at ambient conditions. High temperatures, volatile particles, condensable vapors, and corrosive substances add extra levels of difficulty without changing the underlying problems.

PART 1. THE IMPORTANCE OF PARTICLE SIZE

The Effect of Particle Size on Deposition Losses

If the particle transmission efficiency of a simple bent tube probe is measured with different size particles under constant operating conditions, the result will be a left facing "S" curve with close to 100% transmission for the smallest particles, and close to zero transmission for the largest particles.

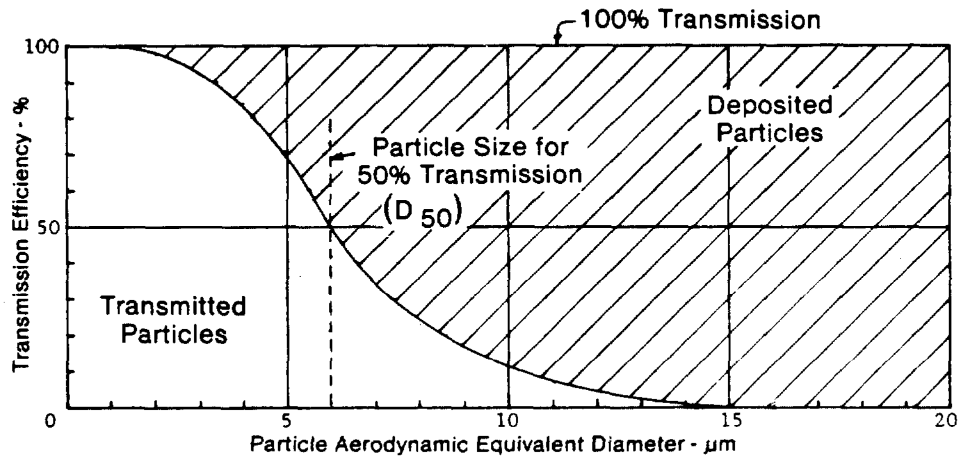


FIGURE 1. Typical Particle Transmission Efficiency Curve for a Simple Bent Tube Monitoring Probe

This means that the probe not only causes a loss of sample (assuming that the deposits cannot be brushed out and added to the filter), but also changes its physical and chemical make-up by allowing a disproportionate amount of the smaller particles to reach the filter. The reason for this behavior becomes obvious when the relationship between particle size, particle mass, and settling velocity is examined.

Particle Characteristics

Particle Size (AED) - µm	0.3	1.0	3.0	10	30
Relative Mass	.027	1.0	27	1000	27,000
Settling Velocity (cm/sec) [5]	.0004	.0035	.03	0.3	2.7

TABLE 1. The Relative Mass and Settling Velocity of Airborne Particles from 0.3 to 30 µm.

The size of an airborne particle usually is expressed in terms of its "aerodynamic equivalent diameter" or "AED", measured in micrometers, or millionths of a meter (symbol µm). By definition this is the diameter of a unit density sphere that has the same settling velocity as the actual particle. This concept permits us to think of particles as simple unit density spheres; permits us to measure them by the way they behave in cascade impactors and aerodynamic particle sizers; and permits us to measure the performance of monitoring equipment from tests with laboratory generated spherical particles (either liquid or solid), which are held within a narrow size range and greatly simplify test work [5b].

Because the mass of a sphere varies with the cube of its diameter, a relatively small range of particle sizes accounts for an enormous range of particle mass and particle behavior. In particular, notice in Table 1 how an increase in particle size from 0.3 to 30 µm results in a 1,000,000-fold increase in mass, and a 7,000-fold increase in settling velocity.

Particles below 1 or 2 µm have such little mass and low settling velocities that they behave almost like a gas, and will follow air currents with little effect of gravity and inertia. Particles above 1 or 2 µm, on the other hand, act increasingly like grains of sand; are influenced to a considerable extent by gravity; and tend to move in straight lines instead of following air currents around bends and elbows. This explains why the transmission efficiency of an extractive monitoring probe drops off rapidly with increasing particle size. It also explains why large particles act differently than small particles in exhaust ducts and stacks.

The reason that different size particles frequently have different chemical and physical properties goes back to their origins. Particles below 1 µm usually are condensed gases (fume and smoke), while particles above 1 µm generally are dispersoids (dust and spray). Thus if the monitoring system does not receive a representative sample it may not provide a true measure of the hazardous nature of the emissions.

Probe Transmission Ratings

One conclusion that can be drawn from Figure 1 is that small particles are transmitted more easily than large ones. A correlary conclusion is that the design of a probe limits the maximum size particle that will be transmitted with reasonable efficiency.

Monitoring probes customarily are rated by the particle size where there is 50% transmission to the collection filter. This is known as the "cut point" or D_{50}. Thus the cut point illustrated in Figure 1 is 6 µm. It also is customary to specify the required performance the same way. This will be discussed more in the next section.

What Monitoring Performance is Needed?

[See Figure 2 on the next page.] Since most monitoring of particulate emissions is done for purposes of human health, the penetration of particles into the human respiratory tract provides important guidance as to the performance that is needed. Some insoluble substances, like silica and asbestos, cause trouble only when they reach the gas exchange region of the lungs (region D in Figure 2). Soluble hazardous substances, on the other hand, may be absorbed by any tissues they touch, including the upper airways. Thus depending on the chemical nature of the emission, it is important to have particle sizes that are significant for human health included on the collection filter.

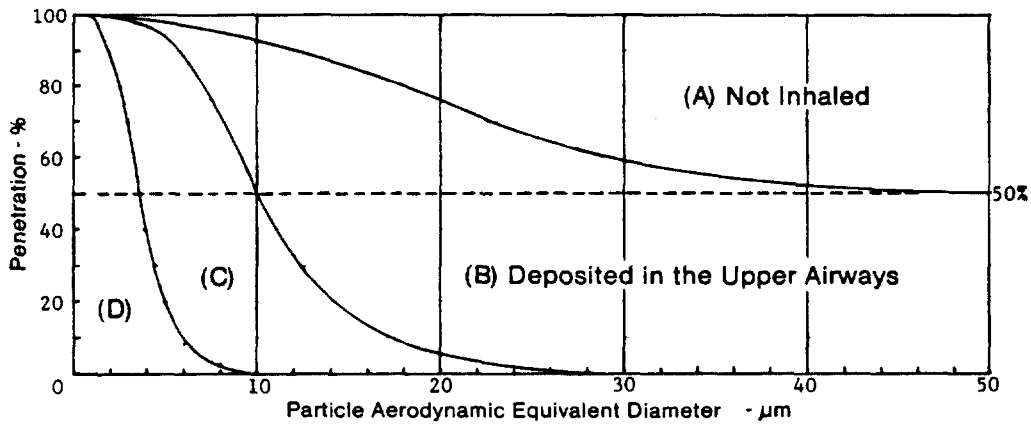


FIGURE 2. Penetration of Particles to Different Parts of the Human Respiratory Tract [6]
(C) is deposited in the tracheobronchial region.
(D) reaches the gas exchange region of the lungs.

A second consideration is the size of the largest particles that are present because, unless they are transmitted to the collection filter, they will deposit in the monitoring probe and plug it over a period of time.

A third consideration is the mass median diameter of the hazardous particles, since frequently most of the mass is in the larger sizes.

A fourth consideration is what is achievable. Based on present knowledge, a reasonable specification is 50% transmission of 10 µm particles. Higher cut points may be possible but should not be specified without experimental assurance that they can be met in practice.

A question frequently arises as to what monitoring performance is needed in the event of accidents, fires, explosions, and HEPA filter failures, where little is known in advance about the nature of the emissions. The State of New Mexico's Environmental Evaluation Group recently studied those questions for the Department of Energy's Waste Isolation Pilot Plant (WIPP) located near Carlsbad, New Mexico, and concluded that "the sample extraction system be capable of delivering at least 50% of the 10 µm AED particles to the filter" [7]. They based their recommendation on (a) the size particles that might be released in the event of a filter break or container spill, and (b) the size particles that could enter and be absorbed by the human respiratory system.

PART 2. WHERE TO EXTRACT THE SAMPLE

The Location Requirements

The three essentials for a good monitoring location are (1) a flow pattern that is stable under all operating conditions; (2) the presence of all particle sizes that must be monitored; and (3) the absence of large scale turbulence. While "rules of thumb" like 10 duct diameters from the nearest flow disturbance are helpful, they tell only part of the story. There still may be pulsations and shifting flow patterns; the particles may be concentrated toward one side of the flow stream; and there may be excessive turbulence. Also, it often is necessary to "make do" with a less than ideal location. Consequently, the only way to verify the choice of location is through field observations and measurements, which must be made before the monitoring probe is designed.

Velocity Mapping

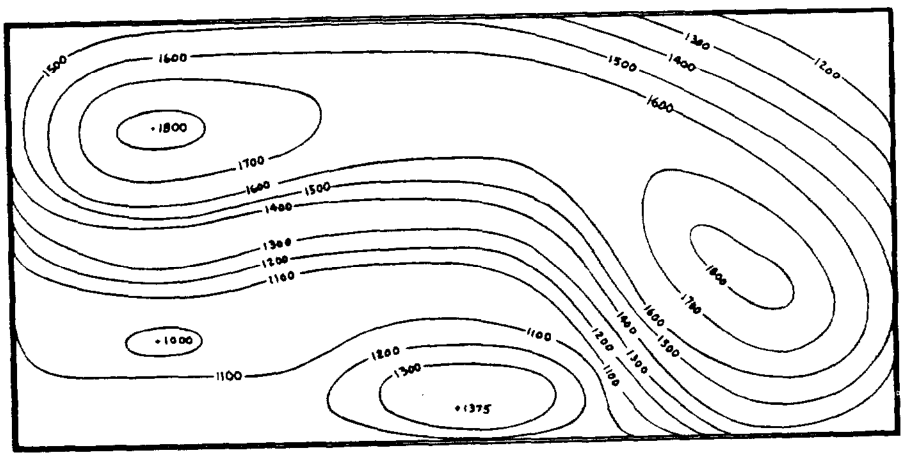


FIGURE 3. Initial Velocity Contours in a 36" x 74" Rectangular Exhaust Duct. Velocities are in Feet per Minute.

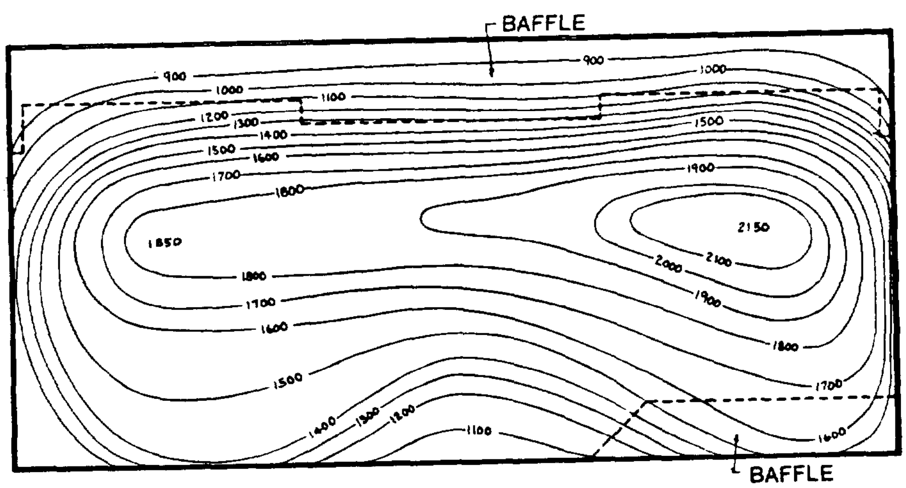


FIGURE 4. Final Velocity Contours in a 36" x 74" Rectangular Exhaust Duct After Installing Baffles 6'-9" Below the Monitoring Plane.

The first step in determining the adequacy of a proposed location is to measure the velocity at a sufficient number of points in the proposed monitoring plane to draw a velocity contour map. These measurements should be made with a directional probe, such as a pitot tube, which can be turned to reveal both the magnitude and the direction of the flow. At the same time, if the flow is pulsating, the amounts of the velocity variations should be noted. Frequently it is necessary to install baffles or vanes ahead of the sampling plane in order to stabilize and straighten the flow.

Figure 3 illustrates the initial velocity pattern in a 36" x 74" rectangular exhaust duct. In addition to the peaks in the upper left and lower right corners, the velocity readings varied by over 50 feet per minute so that making the measurements was difficult. Figure 4 shows the effect of installing baffles along the back wall and in the lower right corner for the purpose of making the flow more symmetrical. As an added bonus, the velocity readings were now nearly steady.

Particle Mapping

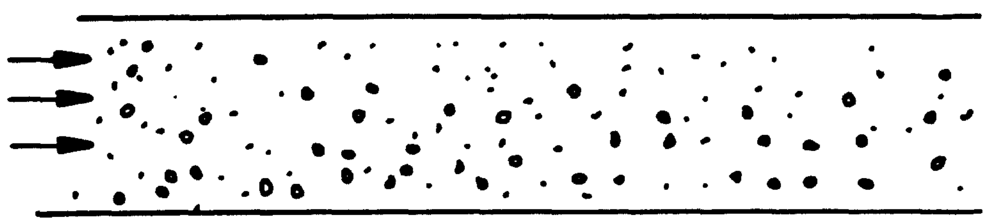


FIGURE 5. Stratification of Particles in a Horizontal Duct [8]

The second step is to locate a region within the chosen plane where all particle sizes are present. For example, measurements in a long horizontal duct will show that the larger particles are more concentrated near the bottom while the smaller particles are distributed almost uniformly throughout. Similarly, measurements made downstream from a 90° elbow will show that the largest particles

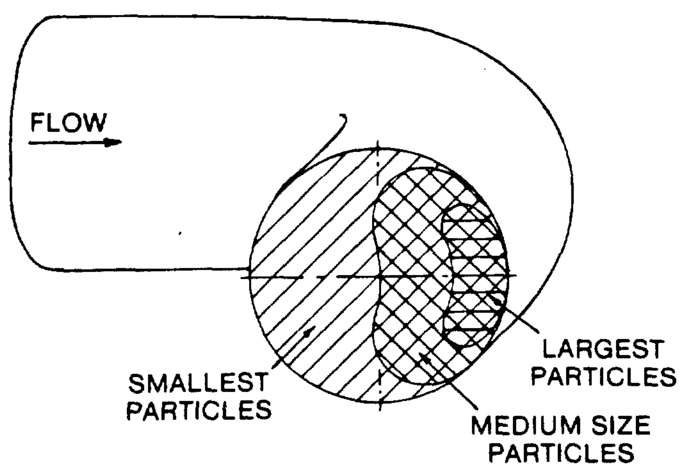


FIGURE 6. Particle Distribution Downstream from a 90° Elbow.

are concentrated near the outside of the elbow, while the smallest particles remain distributed throughout.

In both cases particle stratification is due to the higher settling velocities of the larger particles, which cause them to move faster in a gravitational field. Furthermore, once the larger particles are concentrated a considerable distance is required for them to be redistributed, even when there is turbulent flow in a vertical stack [9].

Three conclusions can be drawn from these observations:

1. In order to monitor the largest particles it is necessary to locate the probe where they will be found;
2. A sample that contains the largest particles will contain all of the smaller sizes as well (providing there has been sufficient mixing distance from the last point of entry);
3. Sampling from the zone of maximum particle size can be beneficial since the high concentration of large particles there will help to compensate for the selective loss of large particles in the monitoring probe.

Particle mapping requires both a supply of test particles and a means of measuring their location in the duct or stack. The test particles are mixed with air to create an aerosol, which is injected sequentially into each of the tributaries that feed into the stack. The location of the different size particles in the sampling plane then is determined by means of an in-situ detector, which can discriminate between different particle sizes. The resulting map serves to show whether there is a single zone of maximum particle size for all operating conditions, or whether there are several areas that must be monitored for thorough coverage.

Large Scale Turbulence

In locations downstream from blowers, fans, louver dampers, and rough wall joints there may be large scale swirls and eddies, in addition to the normal flow turbulence, that require a considerable distance to dissipate [10]. It will be shown later, under "Nozzle Entry Losses," that if these swirls and eddies are larger than the diameter of the inlet nozzle there will be large deposition losses in the nozzle entrance. Consequently, locations that are likely to have large scale turbulence should be avoided if better locations are available.

PART 3A. HOW TO MINIMIZE PROBE TRANSMISSION LOSSES

The Importance of Transmission Losses

The importance of transmission losses may be judged from two examples. Elder, Tillery, and Ettinger [11] tested a standard EPA Method 5 "buttonhook" probe at 1 CFM (28.3 LPM) and found that the internal deposition losses varied from 10% for a 2 µm aerosol to 94% for a 13.4 µm aerosol. Sehmel [12] found that the internal loss of 10 µm particles in a short curved sampling probe (.402" ID x 4.7" long) varied between 8% and 66% depending on the flow rate. Because of losses like this, the designer of a CEPM system must constantly keep them in mind and do everything possible to reduce them.

Although this paper is not intended to be a course in monitoring probe design, there are several important ways of minimizing transmission losses that will be covered under the headings that follow.

The Flow of Best Transmission

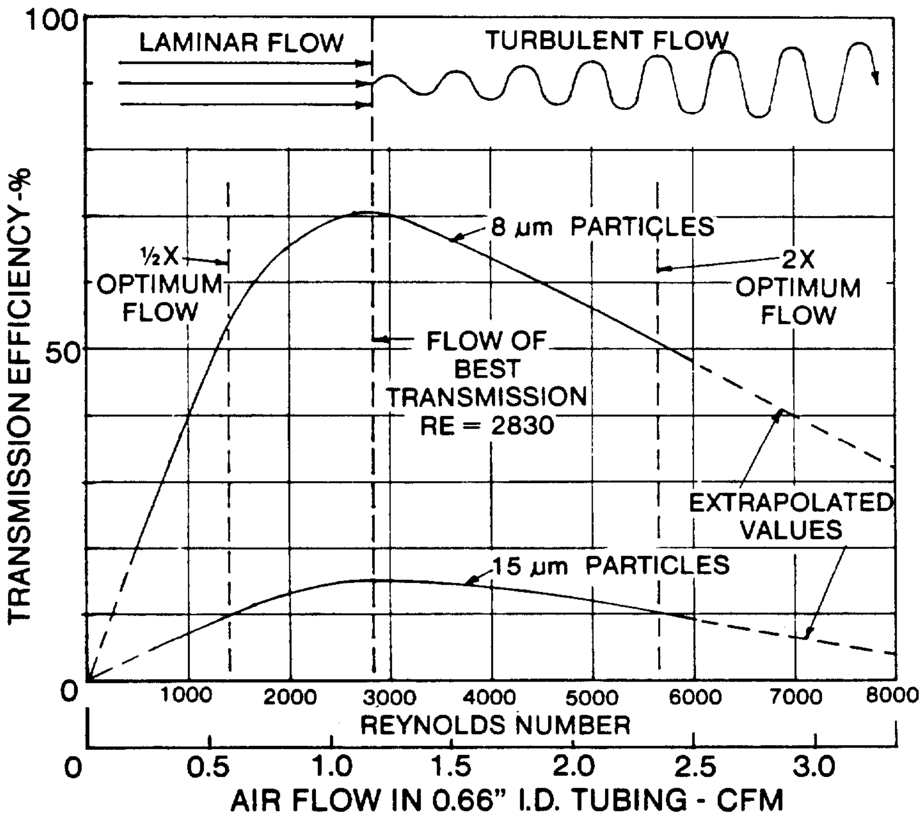


FIGURE 7. The Variation of Particle Transmission Efficiency with Air Flow and Reynolds Number in the Tubing System Studied by Ström.

Investigators have known for over 30 years [13] that the transmission of airborne particles in a tube is helped by increasing the velocity up to a point, after which further increases make matters worse instead of better. By relating this phenomena to the Reynolds number, they learned that the drop off occurs when the flow changes from laminar to turbulent. In laminar flow the streamlines are parallel, so that the greater the velocity the less time the particles have to settle against the walls. In turbulent flow, on the other hand, there is a radial component of velocity due to the turbulence, which accelerates the particles toward the tube walls. The trick is to have the flow as fast as possible without becoming turbulent.

In one of the most useful studies to date, Ström [14] investigated the transmission of different size particles in a system built of 0.66" ID smooth bore stainless steel tubing and found that "the flow of best transmission," as he termed it, occurred at a Reynolds number of 2830 for every size particle that he tested between 2.1 and 15 µm. This is illustrated in Figure 7.

One of the conclusions that can be drawn from Figure 7 is the importance of keeping the flow in a monitoring probe constant at the flow of best transmission, and using other means to keep the inlet velocity equal to the stack velocity for isokinetic sampling. This will be discussed further in the section on "Accomodating Changes in the Stack Velocity," near the end of this paper.

Sizing the Probe for Re = 2830*

MONITORING FLOW RATE	REQUIRED TUBING BORE
0.5 CFM	.280 inches
1.0	.559
1.5	.839
2.0	1.119
2.5	1.398
3.0	1.678
4.0	2.237
5.0	2.796
10.0	5.593

TABLE 2. Required Tubing Bores for Optimum Particle Transmission in Air at Sea Level and 68° F, Based on Reynolds Number=2830 .

By knowing the Reynolds number for the flow of best transmission, it is an easy matter to size a probe to have this Reynolds number at its operating flow rate.

By definition: $$\mathrm{Re} = \frac{V D \rho}{\mu} = 2830$$

Substituting $$V = \frac{Q}{A} = \frac{4\,Q}{\pi D^2}$$

Gives: $$\text{Required } D = \frac{4\,Q}{2830\,\pi} \times \frac{\rho}{\mu},$$

where ρ = air mass density
μ = air viscosity

For air at sea level and 68° F this reduces to: Req'd D [inches] = .5593 Q [CFM], or Req'd Q [CFM] = 1.7879 D [inches]. Designs that deviate very much from these proportions should be looked at with suspicion.

*Caution: Ström's Re = 2830 for the flow of best transmission was determined for 0.66" ID tubing, and has not been validated yet for larger tubes where other factors besides turbulence may be important.

The Effect of Probe Configuration

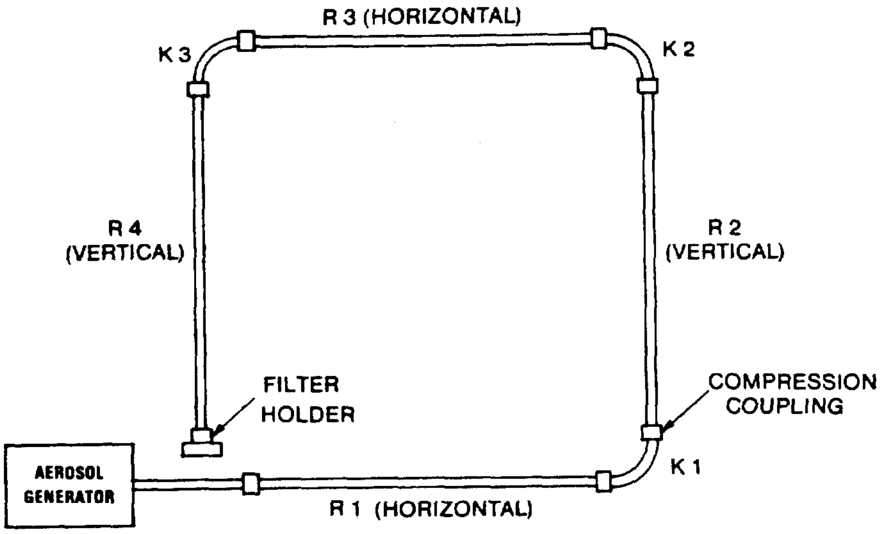


FIGURE 8. Ström's Model Sampling Line.

Monitoring probes are made up basically of horizontal and vertical sections, and tubing bends. Ström obtained some important insight on the relative losses in each of these elements by constructing his tubing system with two horizontal sections, two vertical sections, and three 90° bends, and joining them with compression couplings so that they could be taken apart and cleaned separately. In this system R-1, R-2, R-3, and R-4 were each 78.7 inches (2 meters) long, and were made of smooth bore 0.661" ID stainless steel tubing. K-1, K-2, and K-3 were made of the same tubing and had a 3.15" centerline radius.

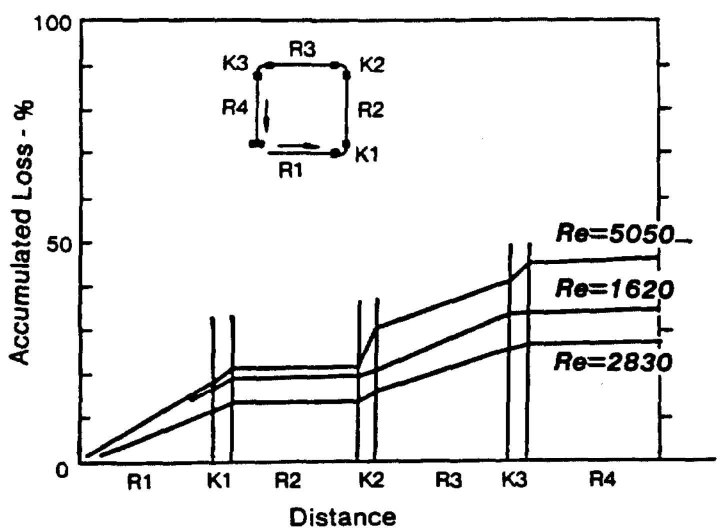


FIGURE 9. Accumulated Loss, in Percentage of Inlet Concentration, Along the Sampling Line. Particle Diameter 8 µm.

From his results, which are plotted in figure 9, it is evident (a) that the lowest losses accurred in the vertical runs, and were almost the same at Re = 1620, 2830, and 5050; (b) that the highest losses occurred in the horizontal runs and were noticeably better at Re = 2830; and (c) that the next highest losses occurred in the 90° bends, where the losses were almost the same at Re = 2830 and 1620, but noticeably worse at Re = 5050.

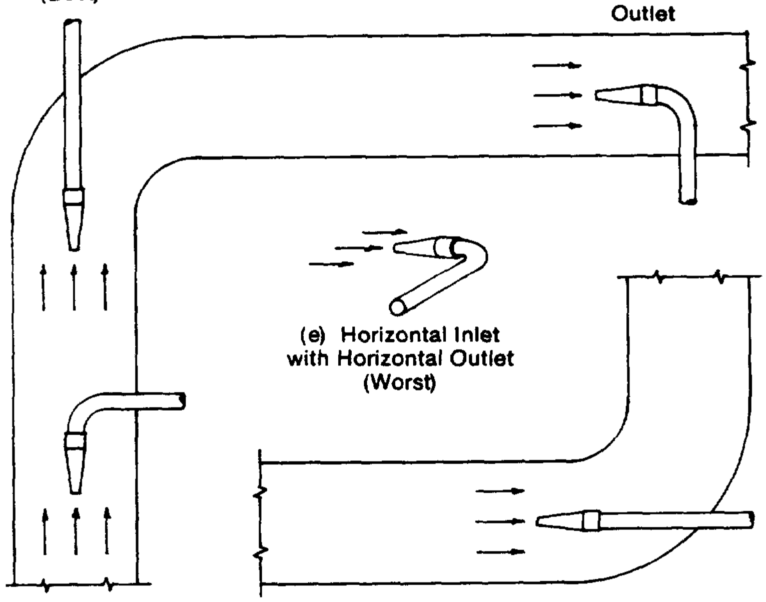


FIGURE 10. Recommended Monitoring Probe Configurations.

When these results are applied to monitoring probe configurations it is possible to make some qualitative choices depending on how much of the probe is vertical or horizontal and whether or not it has a bend. This is illustrated in figure 10, showing that the straight vertical probe (a) is best where it can be used, and that configurations (b), (c), (d), and (e) are progressively worse in that order. Other recommendations are as follows:

1. Use the simplest probe configuration that will do the job;
2. Make it as short as possible by locating the collection filter within inches of the outside of the duct or stack;
3. Use smooth bore seamless tubing, smooth transitions, and large radius bends.

Filter Holder Entry Losses

Monitoring systems for radioactive particles generally have the radiation detector mounted in front of the collection filter and bring the air in through a side tube. Biermann and Velen [15] tested a widely used commercial air monitor with that construction and found that the filter holder entry losses exceeded 50% for 6 µm AED particles. In a subsequent paper Prevo, Biermann, Kaifer, et al [16] reported that the entry losses for 6 µm AED particles could be reduced to below 1% by housing the radiation detector in a streamlined pod, and bringing the flow axially around it. These findings are important because the performance of a CEPM system is only as good as the amount of the sample that reaches the filter.

PART 3B. HOW TO MINIMIZE PROBE ENTRY LOSSES

Sizing the Inlet Nozzle for Isokinetic Sampling

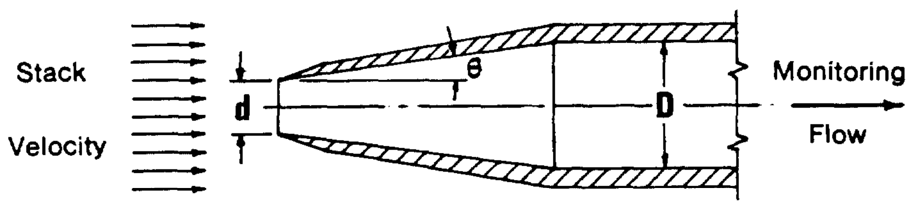


FIGURE 11. Basic Inlet Nozzle Configuration.

In order to make the monitoring probe isokinetic it is necessary to provide one or more inlet nozzles which are sized so that their inlet velocity matches the stack velocity. The required inlet diameter is calculated as follows:

$$Q_{(\text{monitoring flow})} = V_{(\text{stack velocity})} \times A_{(\text{nozzle})} \times N_{(\text{nozzles})}$$

which reduces to

$$d\ [\text{inches}] = 13.54 \sqrt{\frac{Q\ [\text{CFM}]}{N\ [\text{nozzles}] \times V\ [\text{FPM}]}}$$

For purposes of illustration, it will be assumed that the monitoring flow rate is 3 CFM (84.96 LPM) and that the stack velocity is 4000 FPM (2032 cm/sec), since these are typical of the conditions that are found in practice. Secondly, it will be assumed that a series of probes are designed with 1, 2, 3, 6, and 12 nozzles per probe. The resulting nozzle dimensions are shown in table 3. Note particularly how increasing the number of nozzles reduces the inlet diameter of each nozzle.

No. of NOZZLES	FLOW PER NOZZLE	D (tubing)	d (nozzle)
1	3.0 CFM	1.678"	.371"
2	1.5	.839	.262"
3	1.0	.559	.214"
6	0.5	.280	.151"
12	0.25	.140	.107"

TABLE 3. Inlet Nozzle Dimensions for Isokinetic Sampling with a Flow of 3 CFM and Stack Velocity of 4000 FPM. [D is sized for Re=2830.]

The Effect of Inlet Diameter on Entry Losses

A second consideration is the deposition of particles in the nozzle entrance. The classical picture of isokinetic sampling is misleading because it shows parallel streamlines entering a tubular probe, and the particles following them.

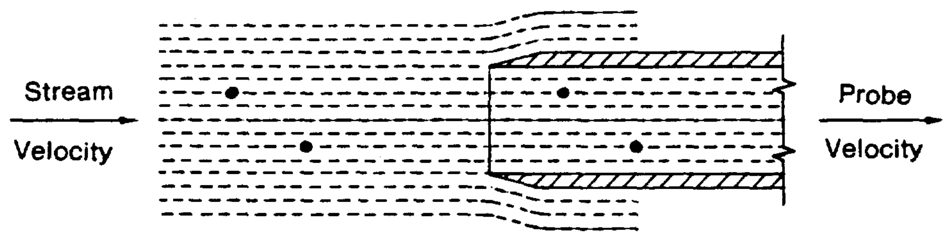


FIGURE 12. *Misleading* Classical Picture of Isokinetic Sampling.

In reality, the flow in most ducts and stacks is highly turbulent, with Reynolds numbers over 10,000, so that the streamlines look more like curly hair, and the particles have a considerable amount of lateral motion. Likewise, the flow inside most inlet nozzles is turbulent, so that the curly hair analogy applies there also [10].

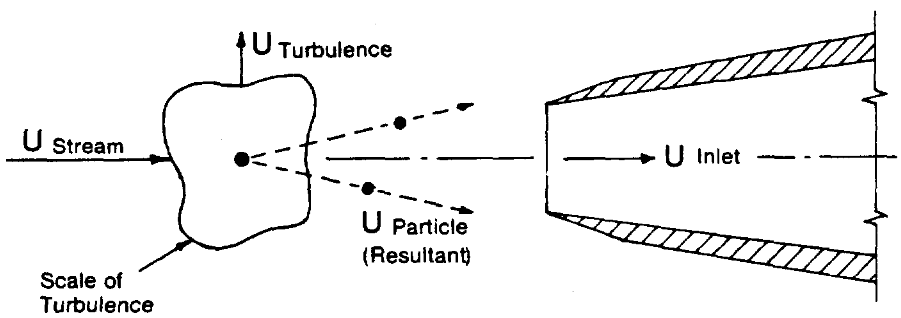


FIGURE 13. Isokinetic Sampling in Turbulent Flow.

A more truthful representation is shown in Figure 13, which was adapted from the work of Wiener, Okazaki, and Willeke [17]. Notice that in turbulent flow the particles move at an angle to the axis because of the radial component of velocity. Also notice that if the scale of the turbulence is larger than the nozzle opening that the particles will have a hard time entering. These effects are illustrated quantitatively in table 4.

ISOKINETIC NOZZLE DIAMETER	Entry Loss for Large Scale Turbulence		Entry Loss for Small Scale Turbulence	
	10 μ PARTICLES	30 μ PARTICLES	10 μ PARTICLES	30 μ PARTICLES
.125"	25%	70%	10%	60%
.219"	15%	55%	6%	45%
.406"	10%	30%	3%	25%

TABLE 4. The Effect of Nozzle Diameter on Probe Entry Losses [17].

One solution to this problem is to use as large an inlet nozzle as possible, by having a single nozzle probe. Another answer that has been suggested is to use an outer nozzle ahead of the probe for the purpose of calming the turbulence, as illustrated in Figure 14.

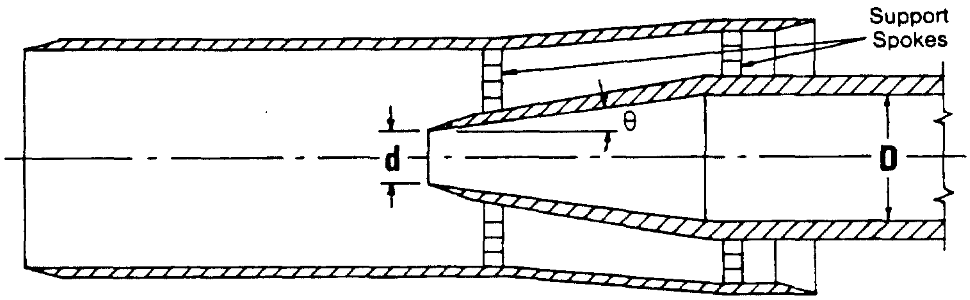


FIGURE 14. Conceptual Drawing of Outer Nozzle for Calming Turbulent Flow.

Before leaving this subject it should be mentioned that the nozzle expansion angle (θ) must be small enough so that the incoming flow can decelerate without separating from the nozzle wall [18]. Frequently this requires an angle of only 4° or 5°, which can be a difficult fabrication problem unless the tubing diameter (D) and the nozzle inlet diameter (d) are large enough to accomodate a husky boring tool.

Advantages of Single Nozzle Probes

One advantage of single nozzle probes already has been mentioned -- that the inlet diameter is larger because there is only one nozzle, which results in lower entry losses. Other advantages are:

- Simpler and less expensive construction;
- Fewer bends;
- Easier to remove for inspection and maintenance;
- Can be located where it will pick up more large particles, which helps to compensate for the selective loss of large particles in the probe;
- Eliminates the problem of dividing the flow evenly between several nozzles;
- Easier to tell when plugging occurs;
- Easier to adjust to changes in stack velocity;
- Permits the use of duplicate probes in critical applications.

The main opposition to single point monitoring comes from a recommendation in ANSI Standard N13.1 [19] that the number of withdrawal points should be proportional to the area of the duct or stack. Even that standard, which was published in 1969, states that "fewer withdrawal points may be used if careful studies show that uniformity of composition exists throughout the cross section of the duct". That requirement will have been met if the flow is stabilized through velocity mapping studies, and if particle mapping is employed to determine whether a single monitoring location is sufficient for all operating conditions.

The trend toward single point monitoring for defining average concentrations is supported by recent studies by Saari and Davini [9], Hanson, Davini, Morgan, and Iverson [20], and Kotchmar, McMullen, and Hasselblad [21].

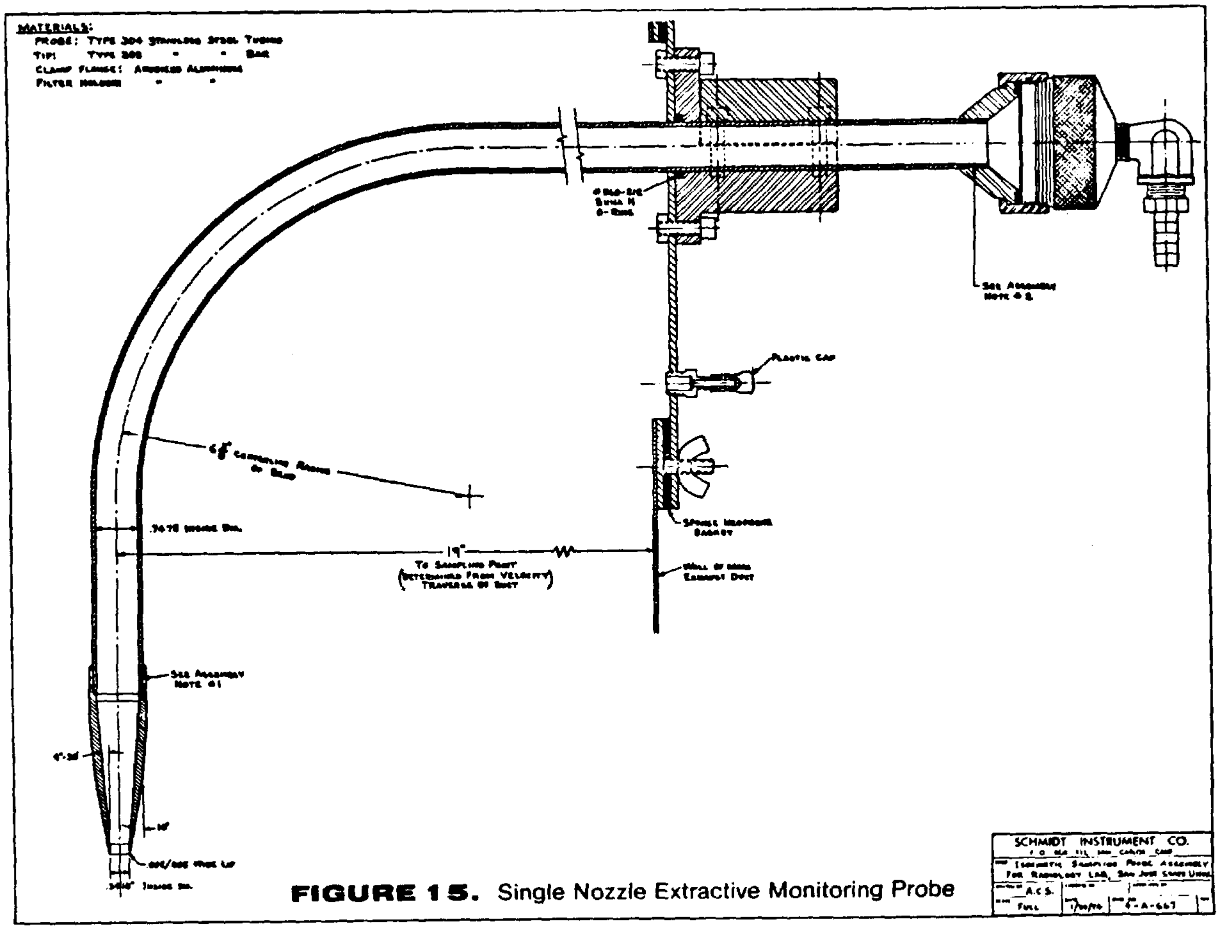


FIGURE 15. Single Nozzle Extractive Monitoring Probe

Figure 15 shows a low loss, single nozzle extractive monitoring probe that was designed according to the principles that have been explained in this paper. It is held in place by a clamp flange that permits it to be moved in and out, and which enables it to be turned so that its inlet is precisely in line with the flow. Its bend radius is 17 times the tubing radius. The nozzle has a .3418" diameter inlet, and a 4°-30' half angle leading smoothly to the .7475" tubing bore. Its filter holder is concentric with the tubing and is located "within inches" of the outside of the stack.

Accomodating Changes in the Stack Velocity

If the velocity in an exhaust stack is constant, a single nozzle monitoring probe may be designed as described in the section on "Sizing the Inlet Nozzle for Isokinetic Sampling," so that the tubing bore (1.678") is optimal for the sampling flow rate of 3 CFM, and the inlet nozzle (.371") is isokinetic at the stack velocity of 4000 feet per minute.

Suppose instead that the stack velocity varies between 2000 and 4000 FPM and occasionally goes to 8000 FPM. Despite all temptation, the monitoring flow should not be changed to keep the inlet isokinetic, since that will lower the transmission efficiency of the probe and result in fewer particles reaching the collection filter. Referring back to figure 7 (on page 9), either halving or doubling the flow will reduce the transmission of 8 μm particles by about 25%, and the transmission of 15 μm particles by about 33%.

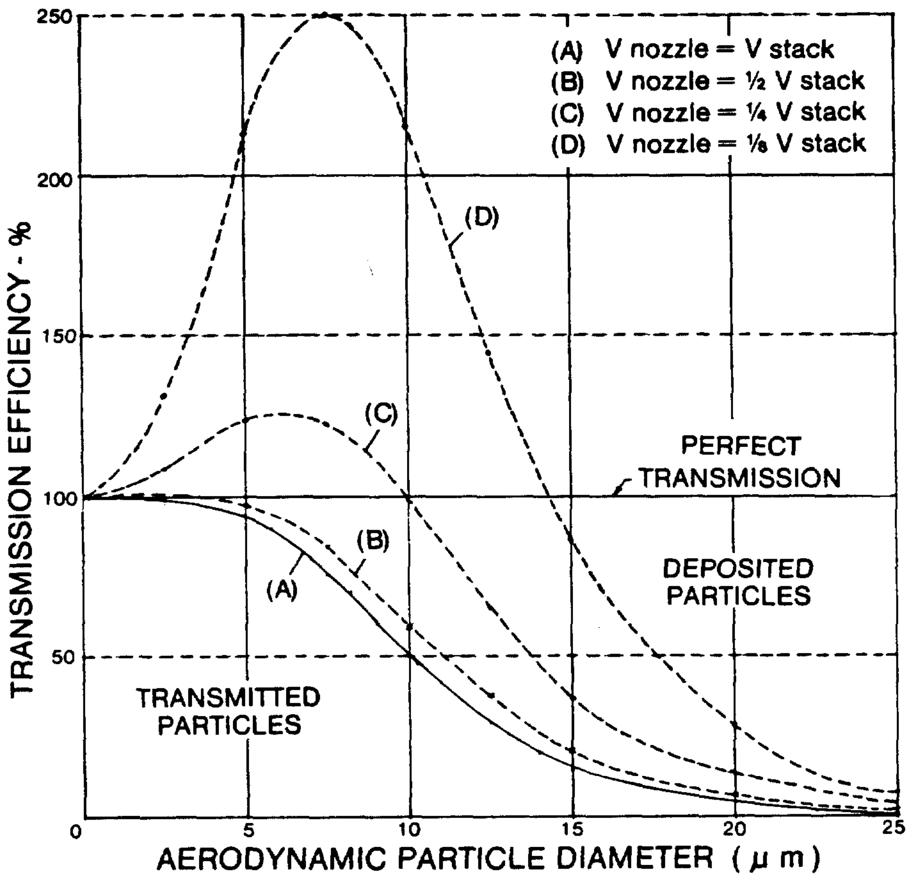


FIGURE 16. Calculated Performance of 3/4" ID Particulate Monitoring Probe with Different Amounts of Subisokinetic Boost*

A better answer is to size the inlet nozzle for 2000 FPM by increasing its diameter to .524", and to observe that operating the inlet at less than the stack velocity (subisokinetic sampling) will increase the intake of large particles and improve the monitoring efficiency. This is illustrated by curves (B) and (C) in figure 16. As an added bonus the larger inlet will help to reduce turbulent entry losses.

Another situation arises when the stack velocity is normally 8000 FPM but occasionally drops to 1000 FPM. Although the inlet nozzle could be designed for 1000 FPM, this would not be good practice because the subisokinetic boost would then be 250% for 7.5 μm particles (curve D in figure 16). A better answer is

---

*Curve (A) in figure 16 is the EPA's PM-10 standard for particulate monitoring. Curves (B), (C), and (D) were calculated from curve (A) by using the equation of Belyaev and Levin [22].

to design the nozzle for 4000 FPM, which gives a reasonable nozzle size with moderate boost (curve B in figure 16), and to use flow substitution (also known as "emission gas recycle") [23] to keep the inlet isokinetic at velocities below 4000 FPM. This requires a special inlet nozzle which is illustrated in figure 17.

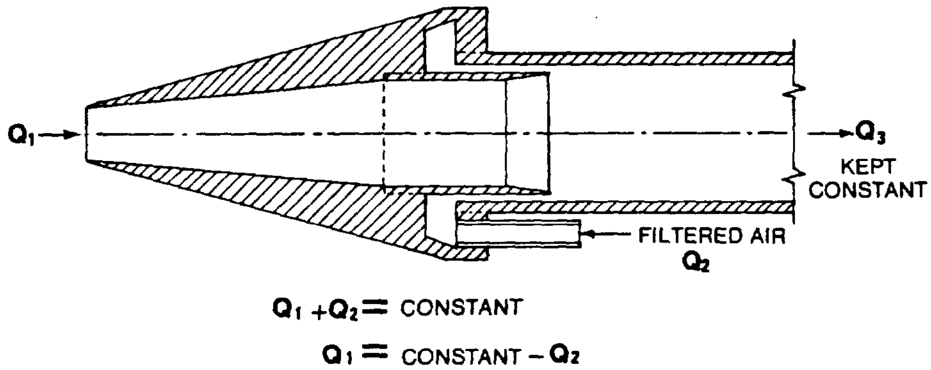


FIGURE 17. Conceptual Drawing of Variable Isokinetic Nozzle in which Flow Substitution is Used to Reduce Q_1 Without Changing Q_3.

Filtered air or gas (Q_2) is introduced into the hub of the nozzle in order to reduce the inlet flow (Q_1) while the total flow (Q_3) is kept constant at the flow of best transmission.

PERFORMANCE TESTING THE PARTICULATE MONITORING SYSTEM

Testing is needed to make sure that the CEPM system has the performance that is needed, and that its measurements will agree with the actual emissions from the stack. This is especially true of new systems, but is also true of existing systems that may not have been performance tested when installed.

Laboratory Testing

The initial performance testing is done in an aerosol research laboratory, and consists of determining the following performance characteristics with the aid of a wind tunnel and fluorescent-tagged monodisperse aerosols:

a. The flow of best transmission;

b. The particle size for 50% transmission (D_{50});

c. The effect of probe configuration;

d. Filter holder entry losses;

e. Nozzle entry losses;

f. The effect of the scale of turbulence;

g. The effect of changes in stack velocity.

Field Testing

The final performance testing is done in the stack and consists of comparing the CEPM system's readings with either (1) the actual aerosol that is present, or (2) a known quantity of test aerosol which is introduced into the stack sequentially from each of the tributaries. This second procedure is a challenging assignment because of the need for generating enough aerosol to obtain measureable readings in the monitoring system [24]. One attractive test material which the author has considered is fly ash from lignite coal. It is inexpensive, has low cohesivity, is nearly spherical, and has a high percentage of its particles in the 7.3 to 12.7 μm size range [25].

Generic Testing

It will be possible to eliminate most of the laboratory testing listed above when tables of performance data are available to assist system designers. Likewise, the cost of field testing will be reduced greatly when convenient test equipment and procedures have been developed. Since this is work that will benefit the general public as well as the owners of emission systems, it deserves to be supported by federal agencies like the Environmental Protection Agency, the Nuclear Regulatory Commission, and the Department of Energy. It also deserves to be supported by the owners of power plants through the Electric Power Research Institute.

SUMMARY AND CONCLUSIONS

Designing a continuous extractive monitoring system for hazardous particulate emissions is a challenging technical problem for which there are no simplistic solutions. A three-part strategy is recommended that simultaneously considers:

1. The importance of particle size on probe transmission, and on the performance that is needed;
2. Where to extract the sample so that it includes all particle sizes that are present;
3. How to minimize transmission and entry losses.

The best way to assure adequate performance is to (a) specify a minimum monitoring efficiency for the largest particles of importance, and (b) require that this be demonstrated through performance tests.

Acknowledgements

The author wishes to thank his many friends, associates, and teachers from whom he received knowledge and ideas that went into this paper.

References

1. U.S. Environmental Protection Agency: Control Technologies for Hazardous Air Pollutants (EPA Pub. 625/6-86/014), Sept. 1986.
2. Oppelt, E.T.: Incineration of Hazardous Waste -- A Critical Review. JAPCA 37:567 (1987).
3. Bullard, C.W.: Issues in Low-Level Radioactive Waste Management. JAPCA 37:1337 (1987).
4. Scott, N., A.M. Garcia, and C. Doran: Experiences of an Extractive Continuous Emissions Monitoring System at Arizona Public Service Co. Unpublished manuscript 86-94P.4. Lear Siegler Measurement Controls Corp., Englewood, Colo. (1986).
5. Dennis, Richard, ed.: Handbook on Aerosols (TID-26608). Springfield, VA: National Technical Information Service, U.S. Dept. of Commerce, 1976.

5b. Berglund, R.N. and B.Y.H. Liu: Generation of Monodisperse Aerosol Standards. Env. Sci & Tech. 7:147 (1973).

6. ACGIH Technical Committee on Air Sampling Procedures: Particle Size-Selective Sampling in the Workplace. Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists, 1985.
7. Rodgers, John C.: Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant (EEG-37). State of New Mexico, Environmental Evaluation Group, Nov. 1987.
8. U.S. Environmental Protection Agency: Industrial Guide for Air Pollution Control (EPA Pub. 625/6-78-004), June 1978.
9. Saari, D.P. and R.J. Davini. Development of a Single Point Strategy for Stationery Source Stack Sampling for Representative Particulate Matter Samples. Final Report. EPA Contract 68-02-3205 to FluiDyne Engineering Corp., 1982.
10. Hinze, J.O. Turbulence, 2nd ed. New York: McGraw-Hill Book Co., 1975.
11. Elder, J.C., M.I. Tillery, and H.J. Ettinger: Evaluation of EPA Method 5 Probe Deposition and Filter Media Efficiency. JAPCA 31:66 (1981).
12. Sehmel, G.A.: Particle Sampling Bias Introduced by Anisokinetic Sampling and Deposition Within the Sampling Line. AIHAJ 31:758 (1970).
13. Friedlander, S.K., and H.F. Johnstone: Deposition of Suspended Particles from Turbulent Gas Streams. Ind. Eng. Chem. 49:1151 (July 1957).
14. Ström, L.: Transmission Efficiency of Aerosol Sampling Lines. Atmos. Envir. 6:133 (1972).
15. Biermann, A. and S. Velen: CAM Particle Deposition Evaluation. Hazards Control Department Annual Technology Review, 1983, Lawrence Livermore National Lab. UCRL-50007-83 (1984).
16. Prevo, C.T., A.H. Biermann, R.C. Kaifer, et al: WOTAMS: A Transuranic-Aerosol Measurement System for Workplace, Stack, or Fence-Line Air Monitoring. Hazards Control Department Annual Technology Review, 1985, Lawrence Livermore National Lab. UCRL-50007-85 (1986).
17. Wiener, R.W., K. Okazaki, and K. Willeke: Influence of Turbulence on Aerosol Sampling Efficience. Authors copy, July 1987. [Submitted to Atmos. Envir.]
18. Reneau, L.R., J.P. Johnston, and S.J. Kline. Performance and Design of Straight Two-Dimensional Diffusers. Report PD-8. Thermosciences Division, Dept. of Mechanical Engineering, Stanford University, 1964.

19. ANSI Standard N13.1-1969: Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities. New York, American National Standards Institute, 1969.

20. Hanson, H.A., R.J. Davini, J.K. Morgan, and A.A. Iverson. Particulate Sampling Strategies for Large Power Plants Including Nonuniform Flow. EPA Contract No. 68-02-1244 to FluiDyne Engineering Corp., 1976.

21. Kotchmar, D.J., T. McMullen, and V. Hasselblad: Adequacy of a Single Monitoring Site for Defining Mean Outdoor Concentrations of Fine Particles in a Demarcated Residential Community. JAPCA 37:377 (1987).

22. Belyaev, S.P. and L.M. Levin: Techniques for Collection of Representative Aerosol Samples. J. Aerosol Sci. 5:325 (1974).

23. Williamson, A.D., R.S. Martin, D.B. Harris, and R.E. Ward: Design and Characterization of an Isokinetic Sampling Train for Particle Size Measurements Using Emission Gas Recycle. JAPCA 37:249 (1987).

24. Schwendiman, L.C.: Appraisal of Airborne Radioactive Effluent Sampling Systems -- Comprehensive Analysis Format and In-Place Sampler Validation. Battelle Pacific Northwest Laboratories Report BNWL-1921 (1976).

25. Farthing, W.E.: Personal communications with the author in April and October, 1986.

DISCUSSION

STROM: The speaker's assumption that a Reynolds number of about 3000 is best for all pipes might not be correct. A calculation, taking into account sedimentation, turbulent impaction, and impaction in bends gives the following conditions for "best transmission" flow:

Pipe Diam. mm	Re	D_{50} μm
10	2000	7
20	3800	10
40	4800	14
80	19000	20
160	26000	28

The calculation assumes a geometry as above. Due to the semi-empirical character of the calculation and the many factors not taken into account, the results above are approximate.

TRACER GAS TESTING WITHIN THE PALO VERDE NUCLEAR GENERATING STATION UNIT 3 AUXILIARY BUILDING

Peter L. Lagus
S-CUBED, A division of Maxwell Laboratories, Inc.

Vincent Kluge
Arizona Nuclear Power Project

Paul Woods
Arizona Nuclear Power Project

John Pearson
NCS Corporation

Abstract

High concentrations of radioactive noble gases (primarily Xe^{133}, Xe^{135}, and Kr^{85}) have been observed on several occasions in the Auxiliary Buildings of both Units 1 and 2 at Palo Verde Nuclear Generating Station (PVNGS). This airborne activity has been detected on various levels of the Auxiliary Buildings, and often has not been identifiable as to source area or initiating activity.

Multiple tracer gas testing, using low concentrations of selected halocarbon gases, was proposed as a method of determining the existence and magnitude of non-ducted airflow. These gases can be detected at very low concentrations and have been used previously in industrial facilities to unambiguously trace diverse air flows.

Three distinct suites of tests were performed. Multiple tracer gas testing during the first two test suites demonstrated migration both along floors and in some cases between floors indicating that ventilation within the source rooms was insufficient to contain potential noble gas release. In addition, floor-to-floor migration was shown to occur through the building drain system, as well as through unsealed penetrations and pipe chases. The third suite provided an explicit demonstration of the isolation ability of the ventilation system while operating in the SIAS mode.

The testing demonstrated the utility and applicability of multiple tracer gas techniques for diagnosing actual operating behavior of nuclear air and gas treatment systems, as well as for disclosing the existence of non-design leakage through unsealed penetrations, ducts, and pipe chases. To our knowledge these techniques have never been used in the nuclear industry to verify that air cleaning and ventilation systems perform as designed.

Te

rat
co
ob
evi

Au
fur
ho
rev
Es
Sig
En

alc
pe
rel
as
an
the

tec
sys
pe
inf
me

Preliminary airflow measurements were performed in the Unit 2 Auxiliary Building to determine whether an airflow balance problem existed. These measurements indicated that although the ducted airflow distribution deviated from design, the degree of deviation was insufficient to suggest that the design non-ducted airflow patterns had been compromised. Thus, the possibility that the HVAC systems' design was not adequate to control airborne radioactive contaminants had to be addressed.

Initial investigations were conducted which included a complete audit of the Radiation Protection Program, review of air sample reports, personnel exposure records and RP Log entries. These investigations concluded that proper administrative controls had been instituted to comply with the requirements of 10 CFR 20.103(b)(2) which states in part:

> "When it is impractical to apply process or other engineering controls to limit concentrations of radioactive material in air below those defined in 10 CFR 20.203(d)(1)(ii), other precautionary procedures, such as increased surveillance, limitation of working times, or provision of respiratory protective equipment, shall be used to maintain intake of radioactive material by any individual within any period of seven consecutive days as far below that intake of radioactive material which would result from inhalation of such material for 40 hours at the uniform concentrations specified in Appendix B, Table 1, Column 1 as is reasonably achievable."

Although these apparently random occurrences of radioactive gas migration were determined not to be reportable in accordance with 10 CFR 50.73 or 10 CFR 20, PVNGS committed to a program which would:

- Evaluate the design of the Auxiliary Building HVAC system with regard to its capability to dilute and purge airborne contaminants during normal plant operation as well as under postulated post-LOCA conditions.
- Perform a detailed design review of the Auxiliary Building Radioactive Waste Drain System and determine its potential contribution to the gas migration problem.
- Identify potential radioactive noble gas source locations.
- Evaluate the potential effectiveness of design modifications to minimize future occurrences of radioactive gas transport via detailed computer modeling of the Auxiliary Building HVAC (Reference 1).

To facilitate the HVAC design evaluation, and to provide the required benchmark for the computer simulation, multiple tracer gas testing was proposed as a method to quantitatively assess the performance characteristics of the existing system.

The Unit 3 Auxiliary Building was chosen for testing since it had most recently undergone final air balancing. Additionally, since Unit 3 had not yet achieved initial criticality, access would be permitted to many areas not readily accessible in the other units due to ALARA considerations.

Test Synopsis.

Actual testing consisted of injecting different halocarbon tracer gases at constant flow rates into selected locations which were suspected sources of airborne radioactive contamination. During each test (of approximate four hour duration), grab samples were obtained throughout the building at discrete times. The samples were analyzed on site for evidence of each tracer gas. These analyses provided a determination of:

- the time of tracer arrival and the tracer concentration at each sample location,
- the tracer concentration at each source location,
- an approximate airflow rate from source to sample point,
- and an indication of air flow patterns.

Three distinct suites of tests were performed. The first suite was conducted with the Auxiliary Building Normal Ventilation in its design configuration, with only three chemistry lab fume hoods operating. The second suite was a repeat of the first series with all five fume hoods operating and plastic drain check-valves (which allow water to drain, but block reverse airflow) installed in the floor drains. The Auxiliary Building HVAC was placed in its Essential Mode of operation to simulate a response to a simulated Safety Injection Actuation Signal (SIAS) condition for the third test suite, and tracer gas was injected into the Engineered Safeguards Feature (ESF) pump rooms.

Multiple tracer gas testing during the first two test suites demonstrated migration both along floors and in some cases between floors, indicating that ventilation system performance within the source rooms was insufficient to contain potential noble gas releases. In addition, floor-to-floor migration was shown to occur through the blocked drains as well as through unsealed penetrations and pipe chases. The third suite of tests provided an explicit demonstration of the isolation ability of the ventilation system while operating in the SIAS mode.

The overall test program demonstrated the utility and applicability of multiple tracer gas techniques for diagnosing actual operating behavior of nuclear air and gas treatment systems, as well as for disclosing the existence of non-design leakage through unsealed penetrations, ducts, and pipe chases. From a larger perspective, three distinct types of information of use within the nuclear air treatment discipline can be obtained via this test methodology:

First, the actual "functioning" air flow patterns can be easily discerned. Often, these patterns are sharply at variance with design airflow patterns.

Second, quantitative assessments of air leakage and airborne contaminant migration can be made. Such quantitative assessments afford definitive health and safety calculations to be undertaken with confidence. This type of test has definite applicability for control room habitability envelope verification.

Third, quantitative knowledge of airflow patterns and flow rates can be used as constraints on numerical ventilation models which attempt to calculate ventilation behavior from measured pressures and airflows.

To our knowledge, these multiple tracer gas techniques have never been used in the nuclear industry to verify the performance of air cleaning and ventilation systems.

II. General Plant Description and Project History

Site Description.

The Palo Verde Nuclear Generating Station (PVNGS) is located on a 4,080 acre site approximately 55 miles west of downtown Phoenix, near the town of Wintersburg, Arizona. Palo Verde is owned by the seven utilities that comprise the Arizona Nuclear Power Project (ANPP). These utilities are: Arizona Public Service, which operates and manages the facility, Salt River Project, Southern California Edison, El Paso Electric, Public Service of New Mexico, Southern California Public Power Authority and Los Angeles Department of Water and Power.

Fully operational, the three identical, standardized 1,270 nominal net megawatt pressurized water reactor units give the plant a total generating capacity output of 3,810 megawatts, which is enough power to meet the electrical needs of approximately 4 million people.

Project History.

A construction permit was issued to the project by the Nuclear Regulatory Commission (NRC) on May 25, 1976 and construction began on June 10 that same year. Palo Verde Unit 1 entered commercial operation on January 1, 1986.

Unit 2 went into commercial operation on September 19, 1986 and set a national industry record in its first month of commercial service by producing more electricity in a single month (987,300 gross megawatts) than had any other single nuclear unit in the U.S. previous to that time.

Palo Verde Unit 3 established a new industry standard by successfully completing its initial Power Ascension Test Program in only 43 days and commenced commercial power operation on January 8, 1988. In March of 1988, Unit 3 generated 995,400 megawatt-hours of electricity to better the national record previously set by Unit 2. And on June 30 1988, Unit 3 completed its 182nd consecutive day of power operation to mark the longest continuous run by any American manufactured nuclear plant in the world during the first year of operation.

Auxiliary Building Description.

The auxiliary Building is a multi-story, reinforced concrete structure approximately 139 feet by 194 feet. It is locate adjacent to the containment building but is physically separated from it. It has a two-level basement extending approximately 60 feet below grade. The building rises to about 56 feet above grade at its highest point. The Auxiliary Building primarily houses the Engineered Safeguards Feature (ESF) and Chemical and Volume Control System (CVCS) equipment, and the power block controlled access facility.

Auxiliary Building HVAC Description.

The Auxiliary Building ventilation system is designed to provide a controlled environment to ensure the comfort and safety of personnel and to maintain the integrity of equipment. Conditioned outside air is distributed throughout the building. The design of the ventilation system is such that, during normal plant operation, air is directed from areas of lower to areas of potentially higher airborne activity.

The normal ventilation system consists of two outside air supply units, multizone air handling units for the access control area, a local recirculating air handling unit for the CEDM control system, MG set rooms and charging pump rooms, two ANSI N509 exhaust filtration units, and exhaust fans for the laboratories. A preset differential between the total system supply airflow and total building exhaust ensures that the Auxiliary building is maintained at a slightly sub-atmospheric pressure to preclude unmonitored radioactive releases to the atmosphere.

During post LOCA operation, the ESF equipment and auxiliary feedwater pump rooms are automatically isolated from each other and from the Auxiliary Building normal HVAC system on receipt of a SIAS signal. Ventilation for the spaces below elevation 100 feet is automatically transferred to the Fuel Building Essential Exhaust Filtration units which reduce space pressure to a measurable negative pressure.

III. Technical Background

Tracer Gas Measurements.

Tracer gases have been used to measure air infiltration and ventilation characteristics of buildings for about 30 years, and the various procedures have been previously discussed.[2,3,4] Desirable properties of tracer gases have been considered by several authors[5,6] and include detectability, nonreactivity, nontoxicity, and a relatively low concentration in the ambient air. Several techniques used to measure tracer gas concentration are listed in Table 1, along with some of the gases appropriate to each method. Several characteristics of large industrial buildings such as found in nuclear plants influence the manner in which tracer gases are used in these structures. First, because of the large building volumes, the quantity of tracer gas required for a test and its cost become important. The expense depends on the cost per ft^3 (m^3) of tracer gas, the building volume, and the magnitude of measurable tracer gas concentrations. Table 2 shows the range in the maximum building volume that can be measured for one dollar's worth of tracer gas (1985 prices). These volumes range from about 4000 ft^3 (400 m^3) for helium to about 10^6 ft^3 (10^5 m^3) for carbon dioxide and nitrous oxide. The ability to measure SF_6, $CBrF_3$ and PDCH in the range of parts per trillion (ppt) yields measurable volumes of 10^8 to 10^{10} ft^3 (10^7 to 10^9 m^3) per dollar's worth of tracer gas. From this table it is apparent that

Table 1. Tracer gases and measuring techniques.

Technique	Gases
Thermal Conductivity Detector	H_2, He, CO_2
Electron Capture Gas Chromatograph	SF_6, Refrigerants, Perfluorocarbons
Flame Ionization Gas Chromatograph	C_2H_6
Infrared Absorption	CO, CO_2, SF_6, N_2O, C_2H_6, CH_4

Table 2. Tracer gas costs taking detectability into account.

Gas	Detectable Concentration (ppm)	Gas Volume Per Dollar ft^3	Gas Volume Per Dollar (m^3)	Maximum Measurable Volume Per Dollar ft^3	Maximum Measurable Volume Per Dollar (m^3)
He	300	1.4	(0.040)	4×10^3	(1×10^2)
CO_2	1	7.0	(0.20)	7×10^6	(2×10^5)
N_2O	1	2.4	(0.060	2×10^6	(5×10^4)
SF_6	5×10^{-6}	0.13	(3.7×10^{-3})	2×10^{10}	(7×10^8)
$CBRF_3$*	5×10^{-5}	3.7×10^{-2}	(1.05×10^{-3})	7×10^8	(2×10^7)
PDCH**	5×10^{-6}	3.0×10^{-3}	(8.5×10^{-5})	6×10^8	(1×10^7)

* Halocarbon 13B1
** Perfluorodimethylcyclohexane

tracer gases such as SF_6, halocarbon refrigerants, and perfluorocarbons analyzed at ppt, or even parts per billion, are most appropriate for large buildings. These tracer gases are commonly measured by means of electron capture gas chromatography, however, measurements have been performed in large buildings using infrared absorption[7,8] and flame ionization gas chromatography.[9]

Ventilation Test Modes.

There are three principal techniques for quantifying the air leakage/ventilation rates within a structure; namely, the tracer dilution method, the constant injection method, and the constant concentration method.[10] The tracer dilution method is a direct way of measuring the air leakage/ventilation extant within a building under ambient flow conditions. The constant injection method is an indirect method; i.e., it measures the equilibrium tracer concentration within a ventilated area. This concentration can be related to the air leakage/ventilation rate if the tracer release rate is known. The constant concentration method is also an indirect method. It measures the amount of tracer as a function of time required to maintain a constant concentration within a ventilated zone or zones.

The quantity of tracer injected can be related to the ventilation rate. The constant concentration technique requires very sophisticated computer controlled release and analysis equipment. At this time it is primarily a research tool and will not be discussed further.

The tracer dilution method has been used for a number of years to measure air leakage rates.(11) It is particularly useful in a single zone or at most in a small number of closely spaced zones. This technique entails introducing a small amount of tracer gas into a structure and measuring the rate of change (decay) in tracer concentration. The air leakage/ventilation rate (generally air changes per hour, abbreviated ACH) can be determined from the logarithmic decay rate of tracer concentration with respect to time.

The principle of the tracer dilution method for measuring air leakage/ventilation rates may be developed, briefly, by considering the average rate L at which air leaks into a test volume. This must equal the average rate at which air leaks out--unless there is a steady increase or decrease in pressure within the volume. The rate of change in the total amount of tracer in the volume is,

$$\frac{dQ}{dt} = (C_{out} - C_{in})\, L \,, \tag{1}$$

where Q is the total amount of tracer, and C_{out} and C_{in} are the concentrations of tracer outside and inside. If V is the total test volume, Equation (1) may be expressed as,

$$\frac{1}{V}\frac{dQ}{dt} = \frac{dC_{in}}{dt} = (C_{out} - C_{in})\, \frac{L}{V} \,, \tag{2}$$

where L/V is the air leakage/ventilation rate in air changes per unit time. If the outside concentration of tracer is small enough to be neglected, Equation (2) reduces to,

$$\frac{dC}{dt} = -\, C\, \frac{L}{V} \,, \tag{3}$$

where we have suppressed the subscripts, and tacitly assumed that C always refers to the inside concentration. Integrating Equation (3) leads to,

$$C = C_o \exp^{-(L/V)\,t} \,, \tag{4}$$

where C_o is the concentration at time t = 0.
Equation (4) may be re-written to give

$$I = \frac{L}{V} = \frac{1}{t}\, \log_e \left(\frac{C_o}{C}\right) . \tag{5}$$

This equation is the theoretical basis for tracer dilution studies of air exchange. The tracer dilution technique is widely accepted and has been incorporated within ASTM Standard E-741-83.(12)

A second method used to infer ventilation rate entails the use of a constant flow source of tracer gas and measurement of tracer gas concentration build-up. This experimental technique is often called the constant injection method. If a constant flow of tracer S is injected into a volume V, beginning at some time t = 0, then the time rate of change in concentration within the volume is given as,

$$\frac{dC}{dt} = - C\frac{L}{V} + \frac{S}{V} \,. \tag{6}$$

It is, again, assumed that the tracer concentration in the supply air entering the volume is negligible. Solving this equation yields,

$$C = \frac{S}{L}\left[\, 1 - \exp\left(-\frac{L}{V}t\right)\right] , \tag{7}$$

if it is assumed that C = 0 at t = 0. For large values of time, corresponding to steady-state conditions, the ventilation rate at any point is simply,

$$L = \frac{S}{C} \,. \tag{8}$$

For regions in which L/V is a large number (i.e., high ventilation rate), the constant injection technique is easier to use than the tracer dilution method, because tracer concentration decay occurs rapidly in regions of high air change rate. Often this rapid rate of decay precludes the measurement of but a few concentration decay data points in a meaningful time span, while a single measurement after attainment of steady-state in the constant injection method yields an air leakage rate.

It is possible to characterize leakage flowrates from a containment area to adjacent areas by injecting tracer gas into the containment area airflow. Subsequent measurement of tracer gas within non-containment areas would provide positive evidence of leakage between containment and non-containment areas. In addition, since the ventilation rate within the non-containment area is often known, measurement of a steady-state tracer gas concentration would allow calculation of an effective leakage rate L, using Equation (8).

The effective leakage rate can be defined as the fraction of the total leakage from a containment area into a non-containment area. This rate can be inferred by using the steady state concentration technique. Knowledge of this rate allows assessment of potential health hazards. The concentration of any contaminant leaking into a non-containment area from a containment area can be found if tracer concentrations within both the containment and non-containment areas are known. The effective leak rate is then given by,

$$L_{eff} = \frac{C_{non\text{-}containment}}{C_{containment}} \times L \tag{9}$$

where $C_{non\text{-}containment}$ = Concentration of Tracer Gas in Non-Containment Area (Measured)
$C_{containment}$ = Concentration of Tracer Gas in Containment Area
L_{eff} = Effective Leak Rate into Non-Containment Area
L = Non-Containment Area Ventilation Rate

Often it is desired to know the probable concentration of a given airborne contaminant at a number of locations which are separated from a given source location. An injection of tracer at a source concentration C_{source} resulting in a measured tracer concentration $C_{measured}$ at a location of interest, yields a dilution ratio, D, given by,

$$D = \frac{C_{measured}}{C_{source}} \tag{10}$$

Once it is measured, this dilution ratio can provide an estimate of the contaminant concentration likely to be encountered at any given location for any conserved species released within the source region.

Tracer Gas Monitor.

Testing of air samples for the presence of tracer gases in this study was performed by means of a proprietary field-usable four channel electron-capture gas chromatograph manufactured by S-CUBED. One of these units is shown in Figure 1. All output from each chromatographic channel is displayed on a strip chart recorder, where relevant peaks are measured and recorded in a data log. A sample chromatogram is provided in Figure 2.

IV. Experimental Technique

Prior to actual testing, background air samples were obtained by PVNGS personnel utilizing S-CUBED supplied containers. These containers were shipped to S-CUBED for analysis. Comparison of the resulting background air data with known elution times of various halocarbons resulted in the choice of Halocarbon 13B1 (bromotrifluoromethane), Halocarbon C318 (octafluorocyclobutane), and PDCB (perfluorodimethylcyclobutane), as the tracers for this experiment. These tracers can be detected at concentrations at least as low as 200 parts per trillion. Thus, for injection source concentrations of the order of 100 parts per billion or greater, dilution ratios greater than a few hundred could be reliably sensed.

In all, eleven tracer tests were performed during the summer of 1987. The first five tests required approximately two days per test. The remaining six were performed on a one per day basis. A single test consisted of releasing tracer at two or three source locations, and then sampling at a variety of locations within the building at timed intervals. In practice each test was performed as follows:

- Prior to initiation of a tracer injection, air samples were obtained from each sampling and source location and analyzed for any potential background of the tracer gases being used. This measurement was particularly important after the first and each subsequent test to ensure complete tracer gas cleanout by the Unit 3 ventilation system.

- After a background sweep demonstrated a clean environment, injection of tracer gas was initiated at each source location. Air samples were then drawn at intervals from each of the sample locations within the building as well as from the roof at the intake to the B sample train over a four hour period.

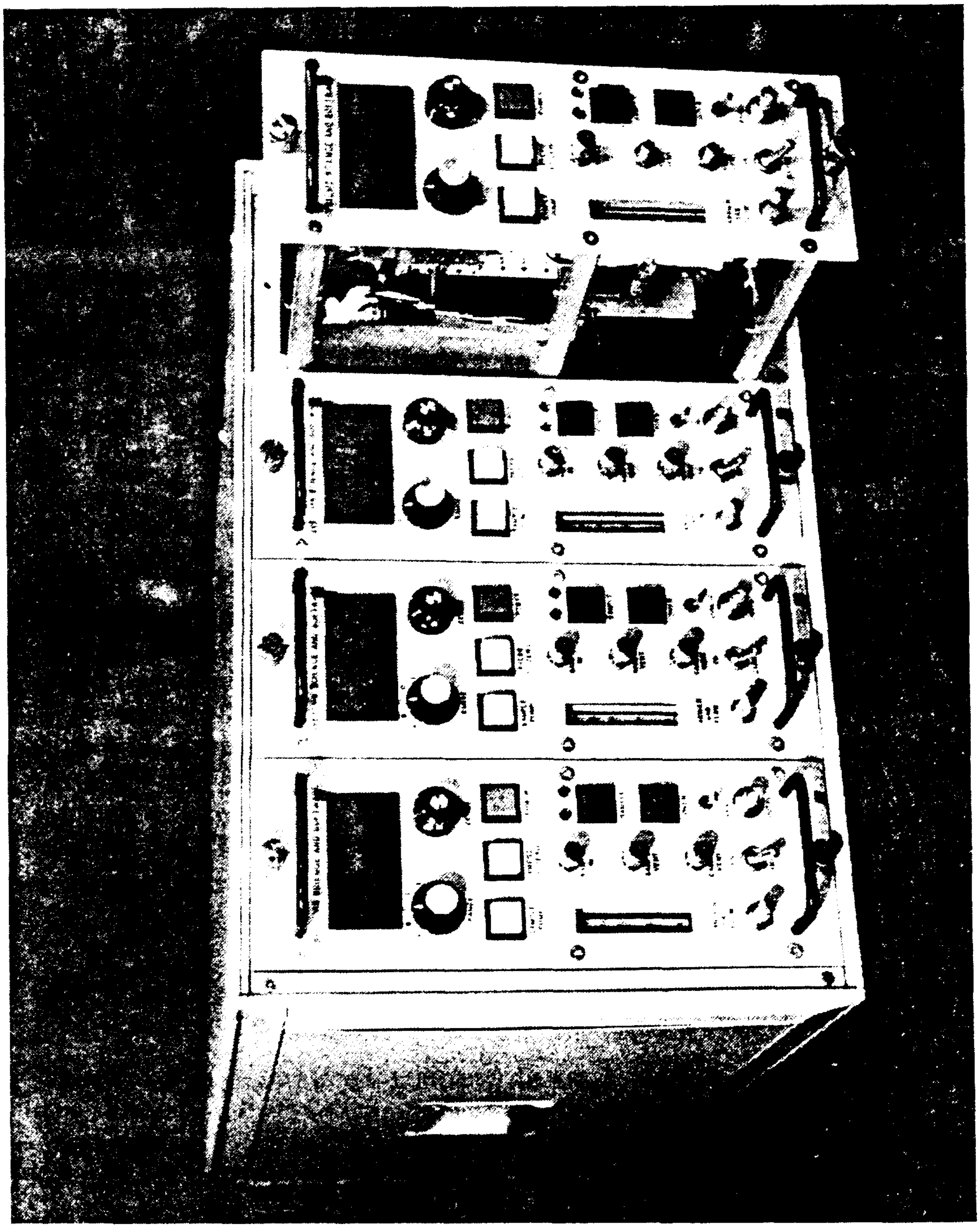


Figure 1. S-CUBED four channel chromatograph used for tracer gas analysis.

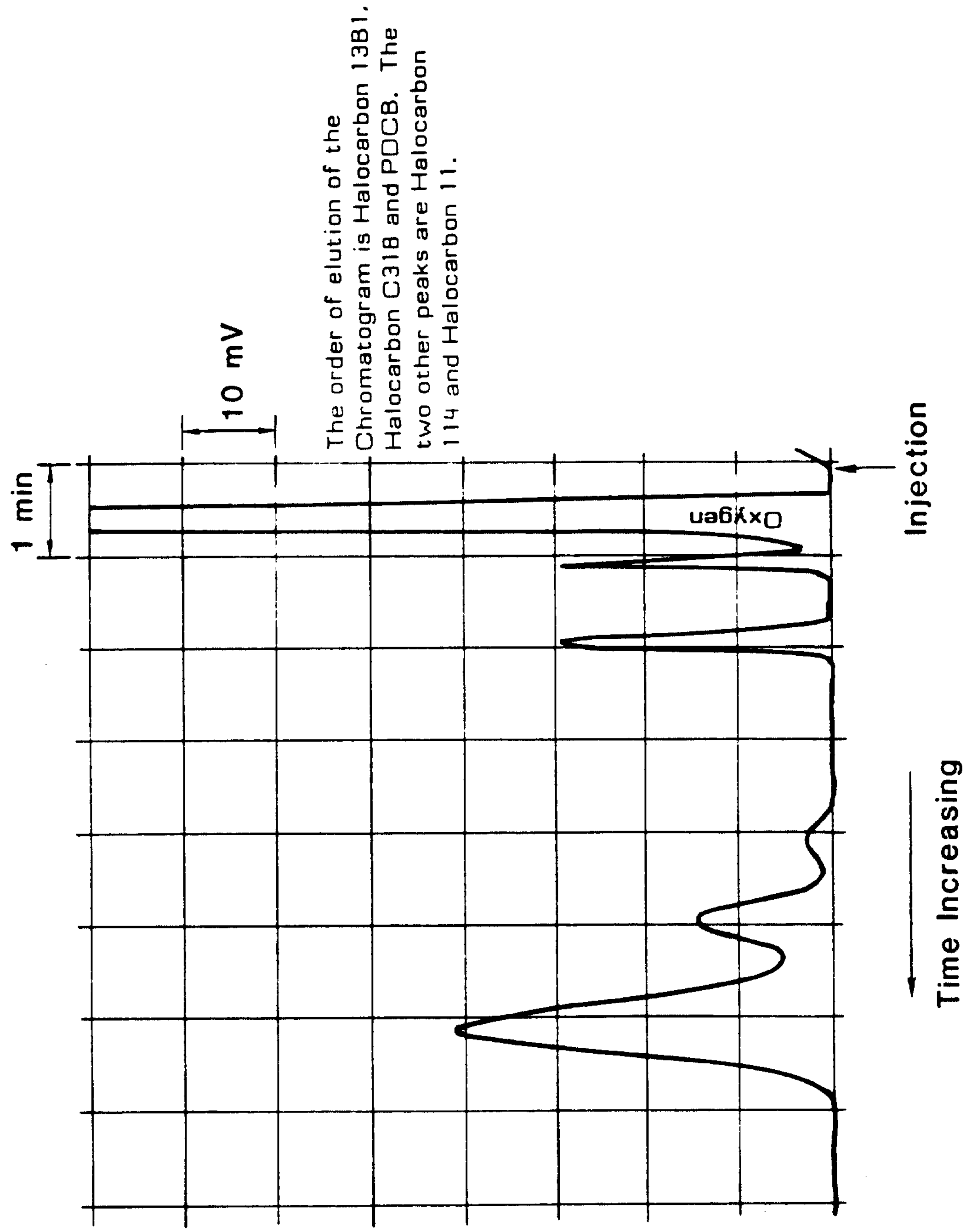


Figure 2. Typical Chromatogram illustrating the separation of the tracer gases.

- After the last suite of samples was obtained, the tracer sources were shut off. The sources were then moved to new locations in preparation for the next tracer experiment.

Originally it was planned to use four electronegative tracer gases as sources, the fourth being Halocarbon 12B1 (bromochlorodifluoromethane). During the initial experiment at the Unit 3 Auxiliary Building, however, a substantial quantity of Halocarbon 114 was discovered. This halocarbon, in fact, masks the arrival of the Halocarbon 12B1. Hence, only the three remaining tracers were used for the testing. It is frustrating to note that not only did the initial background investigation not disclose this halocarbon, but neither did a background sample sweep taken immediately prior to the onset of the first experiment. The Halocarbon 114 background is apparently intermittent. However, when present within the Unit 3 Auxiliary Building, it is generally present in such a high concentration that the use of Halocarbon 12B1 is precluded. For this reason Test I was discarded and no data were retained.

This background interference illustrates the fact that good judgement must be exercised in the choice of tracer gases. Commonly used halocarbons such as Halocarbon 11, 12, 22, and sometimes 113 and 114 are usually not usable as tracer gases. Halocarbons 12, 22 and to a lesser extent 114 are commonly used in air conditioning units, while Halocarbon 113 is a degreasing agent. Halocarbon 11 is used as a challenge agent in the ANSI N510 charcoal filter test and is therefore often found in the nuclear plant gaseous background. Accordingly, Halocarbon 11, as well as these other gases, represents an inappropriate choice for single or multiple tracer gas testing.

Tests II through V were conducted with the ventilation in Unit 3 Auxiliary Building in the normal mode. Two hood fans as well as the spectrophotometer fan were operating in the Hot Lab on level 140. For Test VI through IX, source and sampling locations identical to the first suite were utilized. For these tests, all four hood fans in both the hot and cold labs on the 140' level as well as the spectrophotometer fan were operating. In addition, floor drain seals were installed throughout the Auxiliary Building prior to the onset of testing. Finally Tests X and XI were performed to demonstrate that the ventilation system operating in the SIAS mode can provide ventilation isolation below the 100' level.

Source injection locations for the normal ventilation tests (Test I through IX) were those considered by Palo Verde Engineering personnel to be likely source locations for radionuclides. Experiences in Units 1 and 2 suggested that radionuclide dilutions of a factor of 10 to 100 occurred between various source and sampling locations. Accordingly, source injection rates were chosen to yield source concentrations capable of dilutions in excess of 200. A variety of sample locations were chosen based on conversations with Palo Verde Engineering personnel. Many of these locations corresponded to approximate locations of interest due to radionuclide measurements within either the Unit 1 or Unit 2 Auxiliary Buildings. The remainder were chosen to provide specific flow path information. Note that during the course of this testing, a number of additional sample stations were added during particular tests when additional confirmatory tracer data were deemed desirable. Air samples were usually obtained using glass syringes. Filled syringes awaiting analysis were stored by inserting the syringe needles into a sheet of closed cell foam to prevent loss of tracer concentration by diffusion.

Injection sources consisted of cylinders of compressed gas containing tracer diluted in ultrapure air. Volumetric concentrations for these various source gases ranged from 10^{-3} to 10^{-4}. For the tests, a constant flow of tracer was effected using metering valves operated in a critical flow mode. Tracer injection flowrates ranged from 0.056 SCFM to 0.25 SCFM. These yielded source injection concentrations ranging from 3×10^{-8} to approximately 2×10^{-5}. Actual source concentrations were measured at each source location. Tracer samples were obtained adjacent to the source locations at approximately thirty minutes, one hour, two hours, and four hours into a particular test. These samples provided actual source concentrations.

Two Copus blowers impacting each source at right angles were used to ensure good mixing of the source concentration tracer gas. Care was taken to position the blowers so as not to blow tracer toward the entry way of the particular source location. The sole purpose of the fans was to enhance mixing to allow a meaningful source concentration to be assigned to each location. Undoubtedly the fans would slightly alter the pressure distribution within each source location. They could not however, alter the average pressure within the source room.

During several injections, a single circulating fan was used to provide a more gentle mixing. This was necessary at several locations since they were essentially open to the adjacent level. It was felt that mixing at these locations by use of the high velocity Copus blowers would result in an unnatural spreading of the source gases due solely to the presence of the blowers.

The results of every analysis, even those displaying no evidence of tracer, were recorded in on-site data log sheets. Calibrations were checked at the beginning and end of each test by injecting known concentrations of each tracer gas into each channel. The resulting response was also recorded in the on-site data log sheets.

Prior to the onset of a particular test, doors and openings into the Unit 3 Auxiliary Building which could disturb the normal ventilation flow were labeled with *Test in Progress - Do Not Prop Door Open* signs. In addition, testing was performed on second shift or on weekends when routine personnel movement would be less. In this way it was felt that the overall pressure equilibrium in the building would not be unduly disturbed during testing.

Tests X and XI were designed specifically to test the ability of the ventilation system operated in the SIAS mode to isolate the levels below the 100' level from those at and above the 100' level. For each test, tracer was injected into three ESF pump rooms. Tracer mixing was again assisted by means of two Copus blowers impinging upon each source. Samples were drawn primarily from the 100', 120' and 140' levels in addition to the east and west stairwells at the 100' and 140' level. Two samples were also drawn from the 88' level. One of these was located at the intake to the emergency ventilation duct and one was located at the emergency ventilation filter bank plenum contained in the Fuel Handling Building. Sampling and analysis at both the sample and source locations were identical to that performed in Tests I through IX.

During all testing, meteorological data were logged on the Unit 3 control room monitoring station. These data were not used in the interpretation of the tracer concentration data, although the data were used to confirm that wind induced infiltration remained relatively constant during a test

V. Experimental Results and Discussion

One of the difficulties arising from an experimental program of this magnitude is the question of which data to present and how to present it. Approximately 2200 analyses were performed each of which yielded up to three tracer concentrations per analysis. A detailed discussion of these data therefore would rapidly overwhelm the reader. However, it is instructive to study selected suites of data which can be used to illustrate the various types of information which can be gleaned from the tracer data.

In Figures 3, 4, 5, and 6 we illustrate the results of three distinct tracer release experiments in which the data are used to discern actual airflow patterns. Also, shown on these figures are the anticipated or design airflows. Measured airflow patterns are denoted by broken lines with arrows. The design flow pattern is illustrated using solid lines and arrows. Source locations are denoted by a circled S, while sample locations possess a number adjacent to a circled X. Note that in two of the four tests shown actual airflows depart significantly from design airflows. More generally, eight distinct tracer injection tests were performed which yielded data which could be used to infer airflow patterns extant during normal operation of the ventilation. Of these, five evidenced floor-to-floor migration in which tracer was measured on at least one adjacent level. In some cases tracer migrated two levels from the original injection location. Recall that these injection locations were designed to be ventilation containment areas. In addition, in three of these five, stairwell migration of tracer indicating flow up or down stairwells was also evidenced. No floor-to-floor migration was found in three of the eight tests. Floor-to-floor migration demonstrates that the ventilation system is not maintaining adequate flow conditions to contain potential air borne contaminants on a particular floor.

Of particular interest are the airflow patterns indicated in Figure 5. This test and a similar test both evidenced floor-to-floor migration from the 120' level to the 140' level. Tracer from the source just south of sample station No. 3 was found in the hot lab on the 140' level in measurable concentrations. This migration occurred only when all hood exhaust fans were operating. This floor-to-floor migration was considered to be particularly significant since the 140' level is occupied during normal and abnormal reactor operations. Accordingly, the possibility for floor-to-floor migration of air borne contaminants demonstrated by this test was deemed to be particularly significant.

Figures 3 and 4 graphically illustrate the change induced in the airflow pattern by changing the number of exhaust fans operating and/or adding drain plugs. In Figure 3 for the most part containment is demonstrated. While in Figure 4 the airflow patterns would allow contaminant migration throughout much of the level.

It is possible to utilize the tracer data in a more quantitative fashion than shown in Figure 3, 4, 5, and 6. A plot of equation 7 using values which might typically be found in a nuclear plant building is presented in Figure 7. The plot illustrates the attainment of a steady

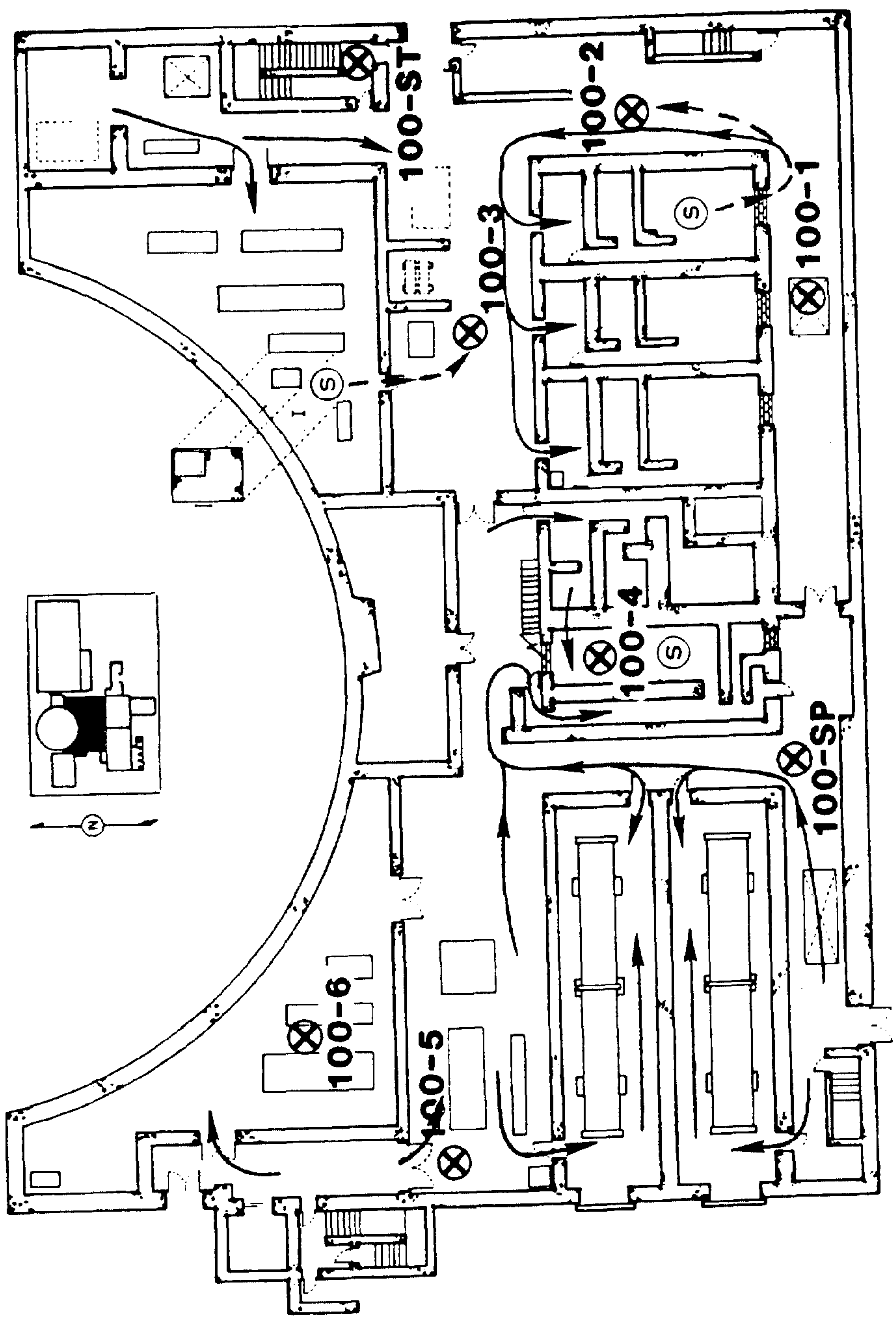


Figure 3. Air flow patterns on the 100' level - 2 exhaust fans operating.

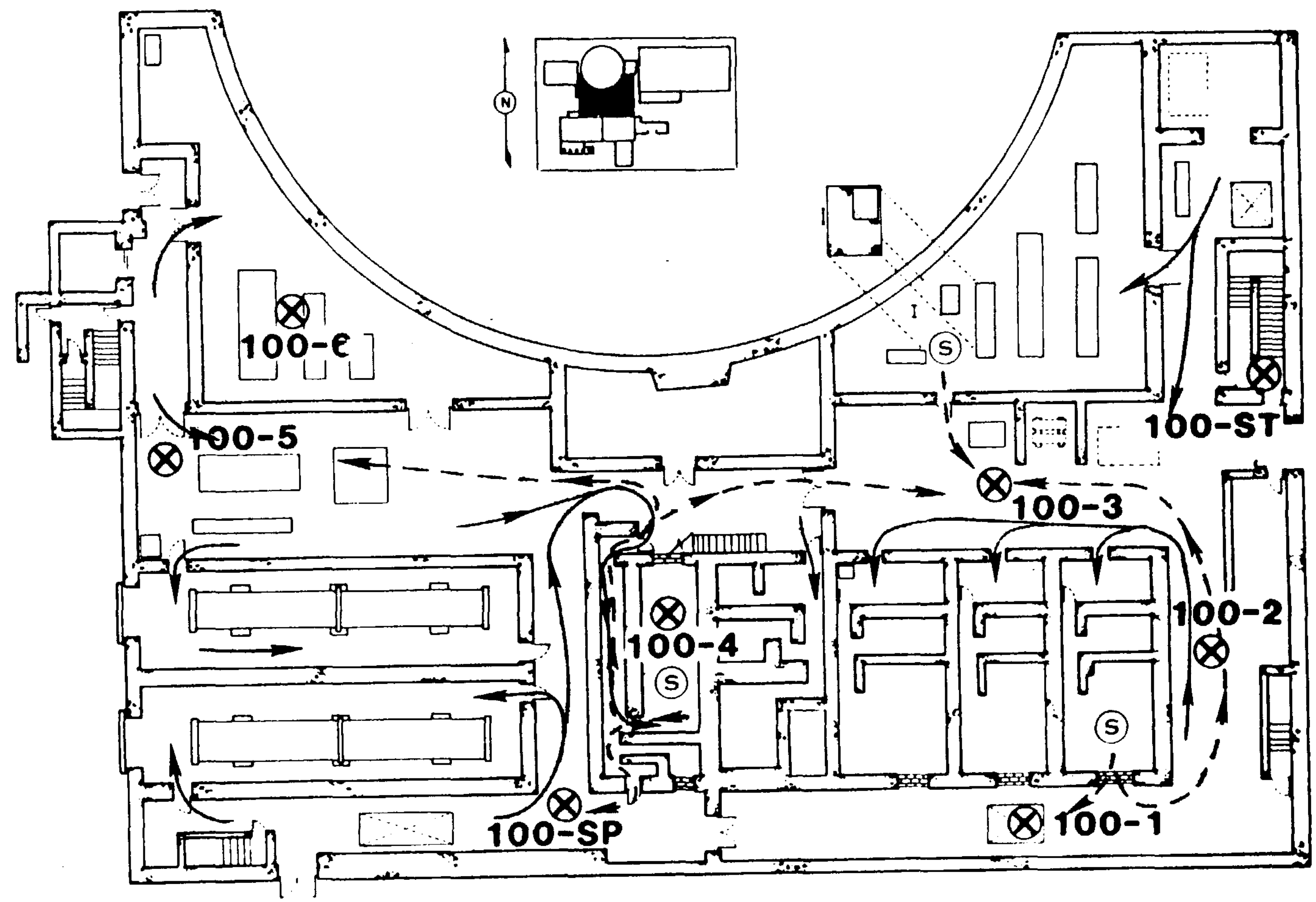


Figure 4. Air flow patterns on the 100' level - 4 exhaust fans operating.

Test IX

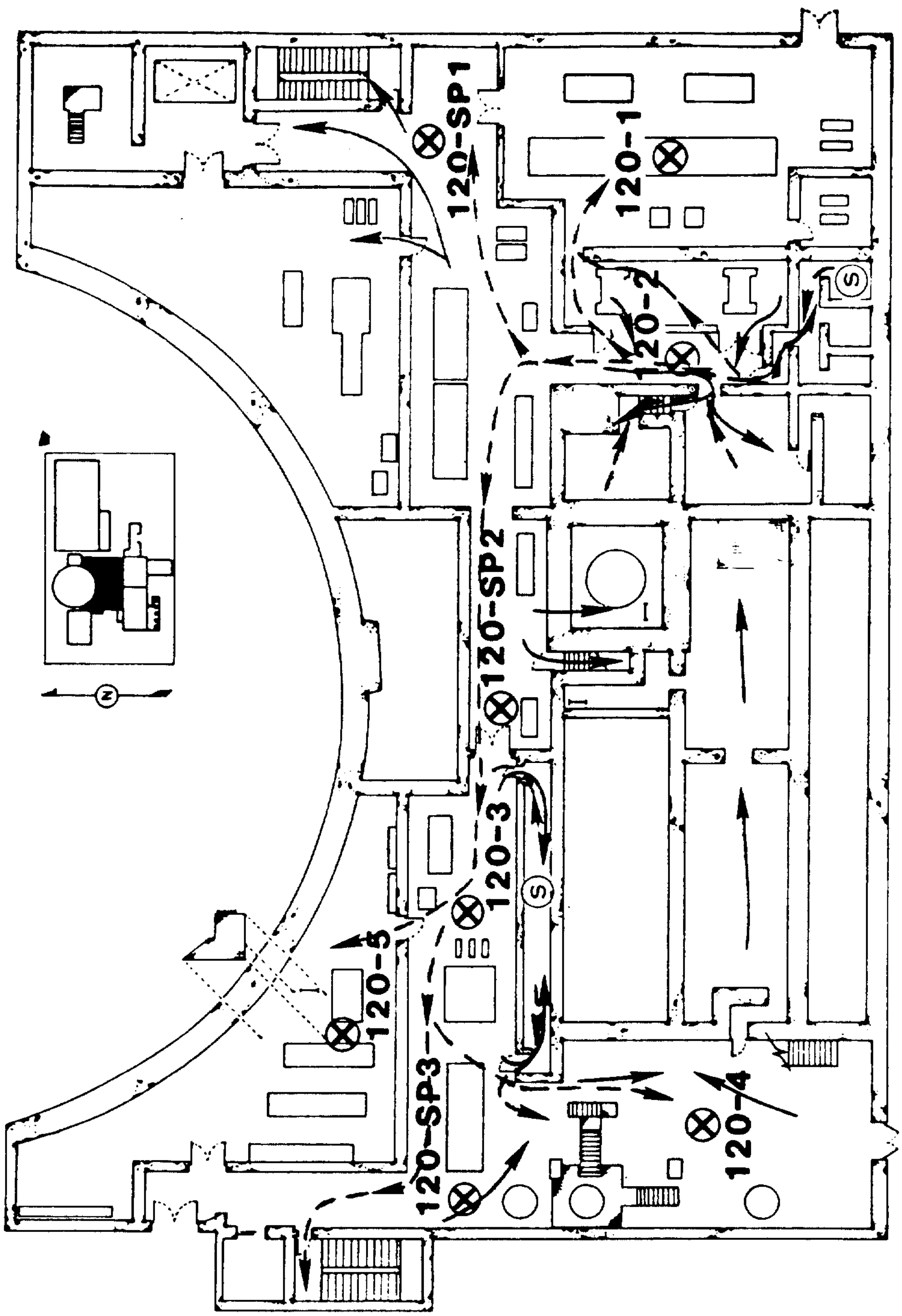


Figure 5. Air flow patterns on the 120' level - 4 exhaust fans operating.

Test VI

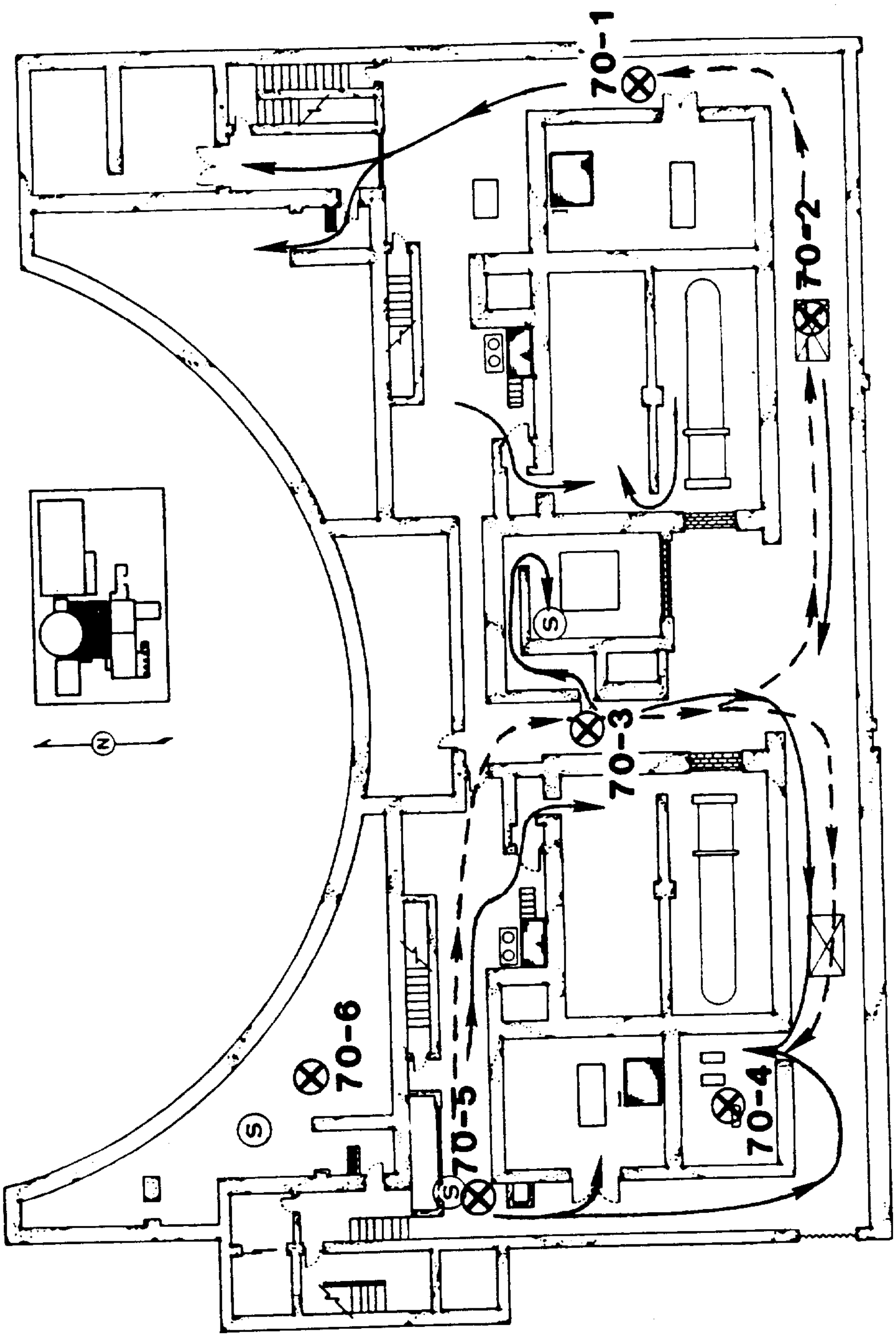


Figure 6. Air flow patterns on the 70' level - 4 exhaust fans operating.

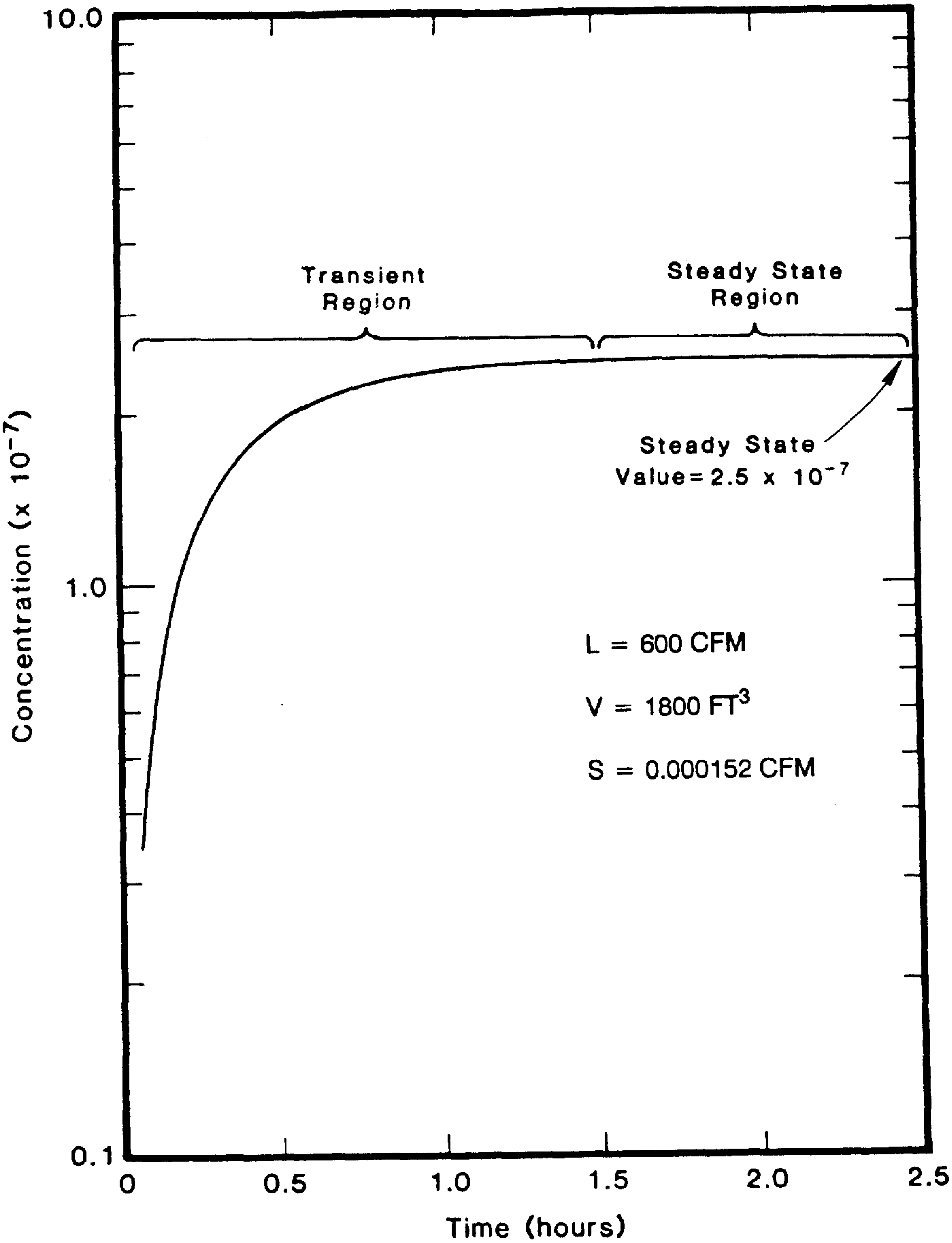


Figure 7. Plot of equation (7) using typical input values.

state concentration from a constant injection source. Any actual tracer data which approximates this profile can be interpreted using equation 7 or 8. Experimentally, plotting the actual concentration data as a function of time yields plots such as illustrated in Figures 8 and 9. In these figures we illustrate actual tracer data, some of which can be interpreted as steady state and some of which cannot. Clearly, for the locations shown in Figure 8 equilibrium is rapidly obtained and therefore, interpretation of these values in terms of equivalent leakages is rather straightforward. For those data shown in Figure 9, all that can be said is that equilibrium was not attained and accordingly these data may not be interpreted in terms of equilibrium concentrations and leakage rates.

For those concentration profiles which have attained steady state, the measured concentration value can be combined with a measured source concentration value to provide a concentration ratio. In Table 3, we provide an abbreviated list of concentration ratios which were calculated using the tracer concentration values which had attained an approximate steady state value or which could be reasonably extrapolated to a steady state. The significance of these data is three-fold. First, the concentration data demonstrate the existence of leakage from a source to a particular measurement location. Second, the ratios themselves can be combined with independent knowledge of ventilation rates within particular areas, to calculate equivalent leakage rates. Third, these data can be used as constraints on any numerical model which attempts to predict the ventilation behavior. As a particular example of the quantitative use of these concentration ratios, reference is made to the floor to floor flow from the 120' to the 140' level which was discussed relative to Figure 5. From Table 3, a concentration ratio of 0.05 was found for flow from the 120' level into the hot lab (station 140-4) on the 140' level. From the Test and Balance report the ventilation rate within the hot lab is approximately 60 CFM. Thus, for this measurement an equivalent leakage of approximately 3 CFM from the 120' to the 140' level is calculated. Detailed tracer measurements demonstrated that this leakage was due to flow up an unsealed pipe chase, as well as flow through a floor drain which had been fitted with a plastic check valve. This particular number was of interest since the 140' level is occupied by unprotected personnel during normal and abnormal operation of the plant. Similar calculations can be performed for other pairs of concentration ratios and other data.

The final tests consisted of two isolation integrity tests. These tests were performed to demonstrate the isolation of levels below 100 feet from those at or above 100 feet during operation of the ventilation in the SIAS mode. For these tests source concentrations within the ESF pump rooms generally exceeded 10^{-5}. Sampling was performed in a number of locations throughout the auxiliary building at and above the 100' level. Tracer samples were taken within the ESF pump rooms which thereby allowed an estimate of the room concentration to be obtained. The absence of tracer gas (everywhere) at or above the 100' level provided strong evidence of ventilation isolation during operation in the SIAS mode.

In fact, since the source concentrations were known, they could be combined with the smallest quantity of tracer which could be detected above or at the 100' level to quantify the amount of leakage from below the 100' level. The absence of measurable halocarbons above the 100' level implied that less than 1/50,000th of the injection gas could have been transported to or above the 100' level. These tests demonstrated the existence of ventilation isolation as well as providing a quantitative estimate of the degree of isolation.

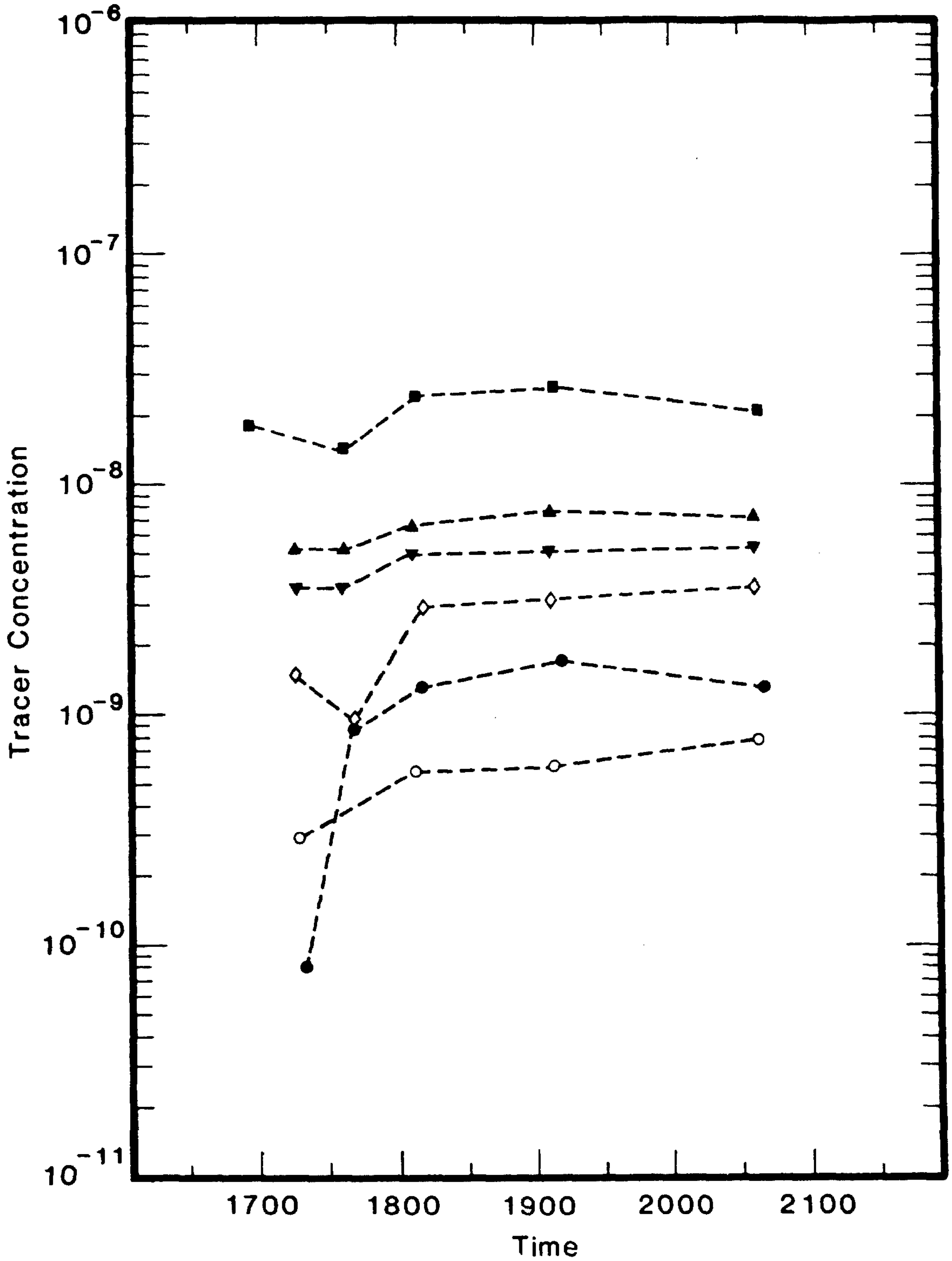


Figure 8. Example of tracer concentration profiles which have attained steady state.

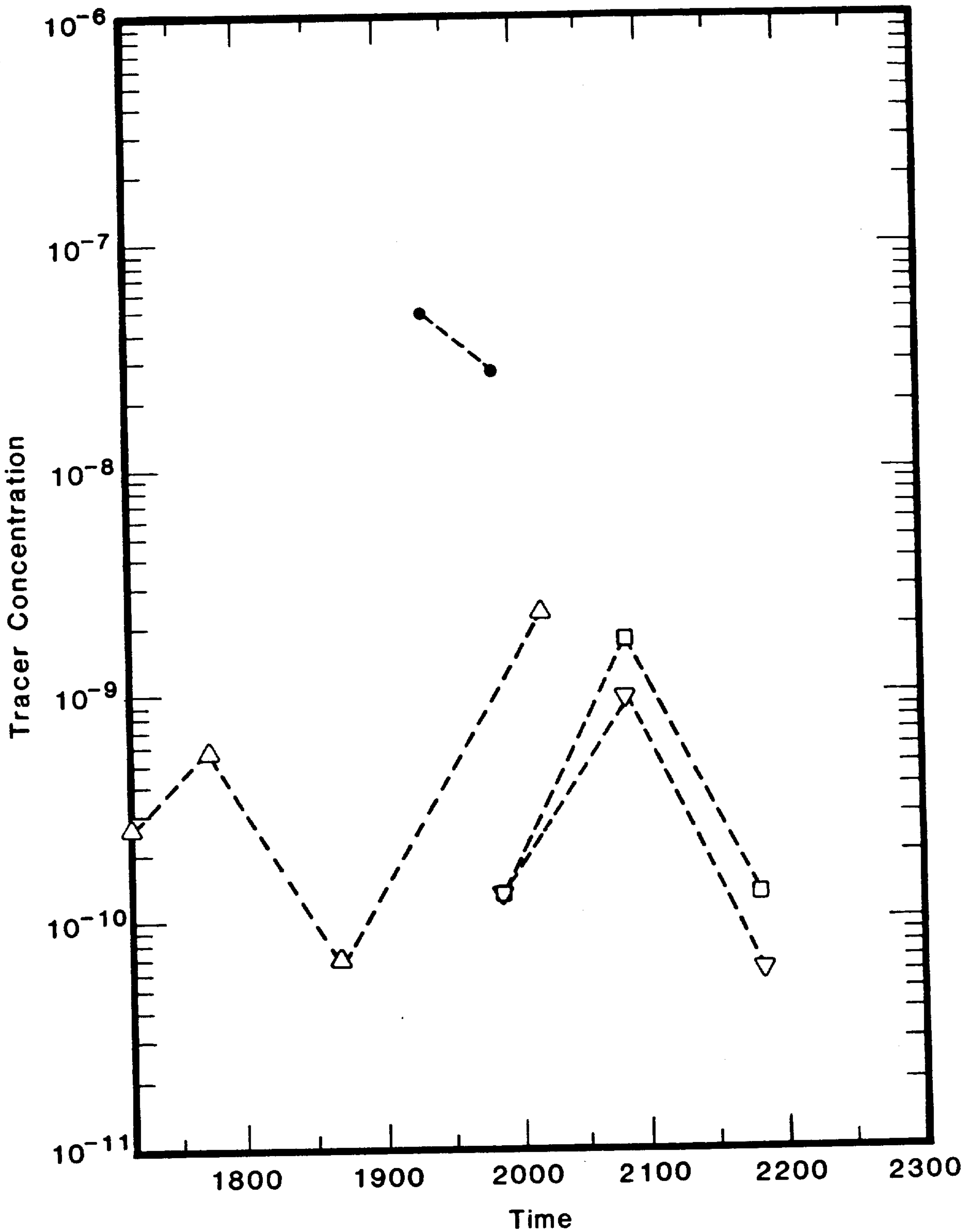


Figure 9. Example of tracer concentration profiles which have not attained equilibrium.

Table 3. Selected tracer concentration ratios.

Test	Location	Tracer Gas	Average	Source Concentration	Concentration Ratio
II	70-1	PDCB	2.9×10^{-10}	28×10^{-9}	0.01036
II	70-2	PDCB	1.75×10^{-10}	28×10^{-9}	0.00625
II	52-2	C318	1.8×10^{-9}	160×10^{-9}	0.0113
III	100-1	13B1	2×10^{-9}	165×10^{-9}	0.012
III	100-2	13B1	1.15×10^{-9}	165×10^{-9}	0.00697
IV	120-3	13B1	4.3×10^{-8}	600×10^{-9}	0.0717
IV	120-2	C318	2.35×10^{-9}	670×10^{-9}	0.00351
V	120-SP2	13B1	3.7×10^{-9}	1170×10^{-9}	0.00316
V	120-SP1	13B1	4.3×10^{-9}	1170×10^{-9}	0.00368
V	40-SP	C318	7.3×10^{-8}	110×10^{-9}	0.664
V	52-1	C318	2×10^{-8}	110×10^{-9}	0.18
VI	70-2	C318	5.1×10^{-9}	87×10^{-9}	0.0586
VI	52-2	C318	1.7×10^{-8}	87×10^{-9}	0.195
VII	100-1	13B1	5.25×10^{-10}	100×10^{-9}	0.00525
VII	100-3	C318	8.1×10^{-10}	90×10^{-9}	0.009
VII	100-5	PDCB	4.8×10^{-10}	240×10^{-9}	0.002
VIII	120-3	13B1	3.6×10^{-8}	370×10^{-9}	0.0971
VIII	120-4	13B1	2×10^{-8}	370×10^{-9}	0.054
VIII	120-2	C318	1.75×10^{-9}	260×10^{-9}	0.00673
VIII	120-3	PDCB	1.9×10^{-9}	300×10^{-9}	0.00633
VIII	140-4	13B1	1.5×10^{-9}	3×10^{-9}	0.05
VIII	140-4	PDCB	2.8×10^{-10}	4.2×10^{-9}	0.0667
IX	120-2	C318	2.35×10^{-8}	1600×10^{-9}	0.0147
IX	120-SP1	C318	7.4×10^{-9}	1600×10^{-9}	0.00463
IX	120-3	C318	6.7×10^{-10}	1600×10^{-9}	0.00042
IX	120-3	PDCB	3×10^{-8}	320×10^{-9}	0.09375
IX	120-4	PDCB	1.8×10^{-8}	320×10^{-9}	0.0563
IX	120-SP3	PDCB	7.5×10^{-9}	320×10^{-9}	0.0234
IX	140-4	PDCB	$^{+}5.2 \times 10^{-10}$	2.6×10^{-9}	NA

$^{+}$ Not at Equilibrium

VI. Conclusions

In the previous sections we have demonstrated that significant quantitative and qualitative information can be obtained about the actual operating characteristics of a complex nuclear air cleaning and ventilation system. We have shown how tracer measurements can be used to document "as designed" airflows within a structure. We have also shown that in many instances quantitative conclusions can be drawn about the ability of the ventilation system to prevent leakage from one area to another either along a particular level or from level to level. Thus, the tracer technique can be useful for demonstrating the existence of and magnitude of migration of airborne contaminants such as of might be of interest in the nuclear power context.

Additionally we have seen how multiple tracer gas techniques can be used to demonstrate ventilation integrity and ventilation isolation in selected regions of a building. Such quantitative information can be used to provide quantitative assurance of hazardous containment integrity during operation of the ventilation system in an emergency containment mode. We have also outlined how multiple tracer gas measurements can be used to provide data which can be directly compared with the predictions of numerical models of a complex ventilation system. Tracer data can serve as strong constraints on the prediction capability of any numerical model. Other areas of potential applicability of multiple tracer gas testing within the nuclear area appear to be:

- control room infiltration,
- duct work in-leakage and out-leakage,
- duct flowrate measurement,
- health and safety monitor location evaluation,
- hazardous containment (containment leak rate) evaluation.

The overall testing program demonstrated the utility and applicability of tracer gas techniques for diagnosing actual operating behavior of containment ventilation systems as well as for disclosing the existence and location of non-design leakage paths. To our knowledge these multiple tracer gas techniques have never been used in the nuclear industry to verify that air cleaning and ventilation systems perform as designed.

Acknowledgements

This work was performed under contract PV87-10929 from the Arizona public Service Company. The authors would like to thank Brian Flanagan and Scott Davis of S-CUBED and Robert Zarbo and John Kerns of PVNGS for their invaluable assistance in the performance of this work.

List of References

1. Palo Verde Unit 3 Noble Gas Migration Study, February 10, 1988, Sargent & Lundy Engineers. Report on Project 7950-07.

2. Sherman, M.H,; Grimsrud, D.T.; Condon, P.E.; and Smith, B.V. 1980. "Air infiltration measurement techniques." in Air Infiltration Instrumentation and Measuring Techniques, proceedings of the First Air Infiltration Centre Conference, Berkshire, UK.

3. Lagus, P.L. 1977. "Characterization of building infiltration by tracer dilution method. Energy, Vol. 2.

4. Ashley, J.L.; and Lagus, P.L. 1984. "Air infiltration measurements in large military aircraft hangers." Measured Air Leakage of Buildings, eds. Treschsel, H.R.and Lagus, P.L. STP 904. American Society for Testing and Materials, Philadelphia.

5. Honma, H. 1975. "Ventilation of dwellings and its disturbances." Stockholm: FAIBO Grafiska.

6. Hunt, C.M. 1980. "Air infiltration: a review of some existing measurement techniques and data." in Hung, C.M.; King, J.C.; and Treschsel, H.R. eds., Building Air Change Rate and Infiltration Measurements. STP 719. American Society for Testing and Materials.

7. Potter, N.; Dewsbury, J.; and Jones, T. 1983. "The measurement of air infiltration rates in large enclosures and buildings." in Air Infiltration Reduction in Existing Buildings, proceedings of the Fourth Air Infiltration Centre Conference. Elm, Switzerland.

8. Zuercher, C.H.; and Feustel, H. 1983. "Air infiltrations in high-rise buildings." in Air Infiltration Reduction in Existing Buildings, proceedings of the Fourth Air Infiltration Centre Conference. Elm, Switzerland.

9. Prior, J.; Littler, J.; and Adlard, M. 1983. "Development of multi-tracer gas technique for observing air movement in buildings." Air Infil. Rev., Vol. 4, No. 3.

10. Lagus, P.L., and Persily, A.K. 1985. "A Review of Tracer Gas Techniques for Measuring Airflows in Buildings" ASHRAE Trans. 91 No. 2.

11. Lagus, P.L. 1980. "Air leakage measurements by the tracer gas dilution method - A review." in Building Air Change Rate and Infiltration Measurement. eds., Hunt, C.M.; King, J.C.; and Treschsel, H.R. STP 719. American Society for Testing and Materials, Philadelphia.

12. ASTM. 1983. ASTM E 741-83, "Standard practice for measuring air leakage rates by the tracer dilution method." Philadelphia: American Society for Testing and Materials.

DISCUSSION

MOELLER: The data in Table 2 in your paper appear to be based on the assumption that there are about 10 cubic feet per cubic meter. The correct value would be about 35 ft^3 per cubic meter. Am I misinterpreting your data?

LAGUS: You may be right, I have not checked that number in five years. As a note, the table included in the printed Proceedings contains corrected entries.

AN ANALYTIC APPROACH TO NOBLE GAS MIGRATION

William J. Adams
Sargent & Lundy
Chicago, Illinois

Dee Pak Bhasin
Arizona Public Service Company
Phoenix, Arizona

Abstract

The purpose of this paper is to discuss an analytic approach used to model noble gas migration in the auxiliary building of a nuclear power plant. This approach uses a detailed computer model of the auxiliary building that has been benchmarked against test data to identify and predict unintended gas migrations in the plant. The end result is an analytical tool that is capable of investigating the effects of potential plant changes made to prevent gas migration.

Because of the many discrete potential gas source locations and the large number of gas migration routes, a detailed model is required. A separate node in the model is used to represent each source location subcompartment. Also included in the model are ducted HVAC supply and exhaust flows for each node and nonducted flow paths allowing gas migration between areas in the plant.

This paper discusses the data required for this approach. Various plant drawings and a plant walkdown were required in order to develop an accurate model of the plant. Subcompartment pressure measurements, ducted flow rates, and tracer test results were required to provide baseline data and benchmarking of the analytical model.

As a result of the computer analysis, specific areas of the plant susceptible to gas migration were identified. The mechanisms allowing this migration were examined and the effectiveness of potential plant changes to mitigate gas migration were investigated using the computer model.

Introduction

With the occurrences of noble gases at the top floor inside the auxiliary building at Palo Verde Nuclear Generating Station (PVNGS)[1], a four-tiered approach was initiated to resolve the problem. This paper details the computer modeling of the building HVAC, floor drains, and nonducted flow paths to track and predict the migration of noble gases.

The modeling goal was twofold; first, to identify the mechanism of noble gas migration and secondly, to evaluate the potential of design modifications to minimize future occurrences.

The auxiliary building at PVNGS is a three-story structure plus two levels below grade. It houses the pumps for the engineered safety features below grade in individual rooms, and the reactor chemical and volume control equipment on the first two floors. The top floor consists mainly of chemistry laboratories, the radiation protection department, and locker rooms.

The building HVAC was designed to supply the amount of conditioned air required to maintain the desired temperature based on heat load due to equipment and/or personnel for each individual room for all elevations. Further, each room is maintained under negative pressure, i.e., more air is exhausted from the room than is supplied. All corridors in the building are provided with supply air which infiltrates into individual rooms and provides for airflow from clean areas to areas of potential radioactivity.

The model was benchmarked using the concentration ratio results determined during the tracer gas tests. After benchmarking, the computer model was modified to reflect changes in the HVAC and floor drain systems made to improve the control of the migration of noble gases. The effects of these potential changes were investigated by comparing the new predicted concentrations against those of the benchmarking. The development of a realistic computer model of the airflow in the auxiliary building and the use of this model to predict noble gas concentrations in the building resulting from postulated discrete noble gas sources is further discussed.

Inputs to Model

In order to develop an accurate model of the auxiliary building, a detailed review of various drawings was performed. The drawings examined in this review included general arrangements, door schedules, penetration schedules, HVAC system schematics and drain line system schematics. These drawings were reviewed in order to identify nonducted flow paths. Nonducted flows in the auxiliary building occur through openings between adjacent areas such as nonsealed penetrations, doorways, hatchways, gratings, and stairwell openings. A walkdown was also performed to identify additional nonducted flow paths not shown on drawings following the initial tests.

The test and balance HVAC system ducted flow rates were also required as input, as were node pressure measurements for the test and balance HVAC system configuration. This input was used to obtain initial estimates of nonducted flow rates and ducted flow path resistances.

Finally, a series of tracer tests, which measured tracer gas concentrations at discrete locations in the auxiliary building, were needed. The tracer gas test results were used to fine tune and benchmark the computer model.

Method of Analysis

The detailed model of the auxiliary building was prepared in the following manner. To obtain calculated results consistent with the tracer tests, each tracer source and measurement location was modeled as a separate node. The nodalization schematic of the auxiliary building utilized is presented in Figure 1. The nodalization schematic of the floor drain system, which was open and represented a network of migration paths, is presented in Figure 2.

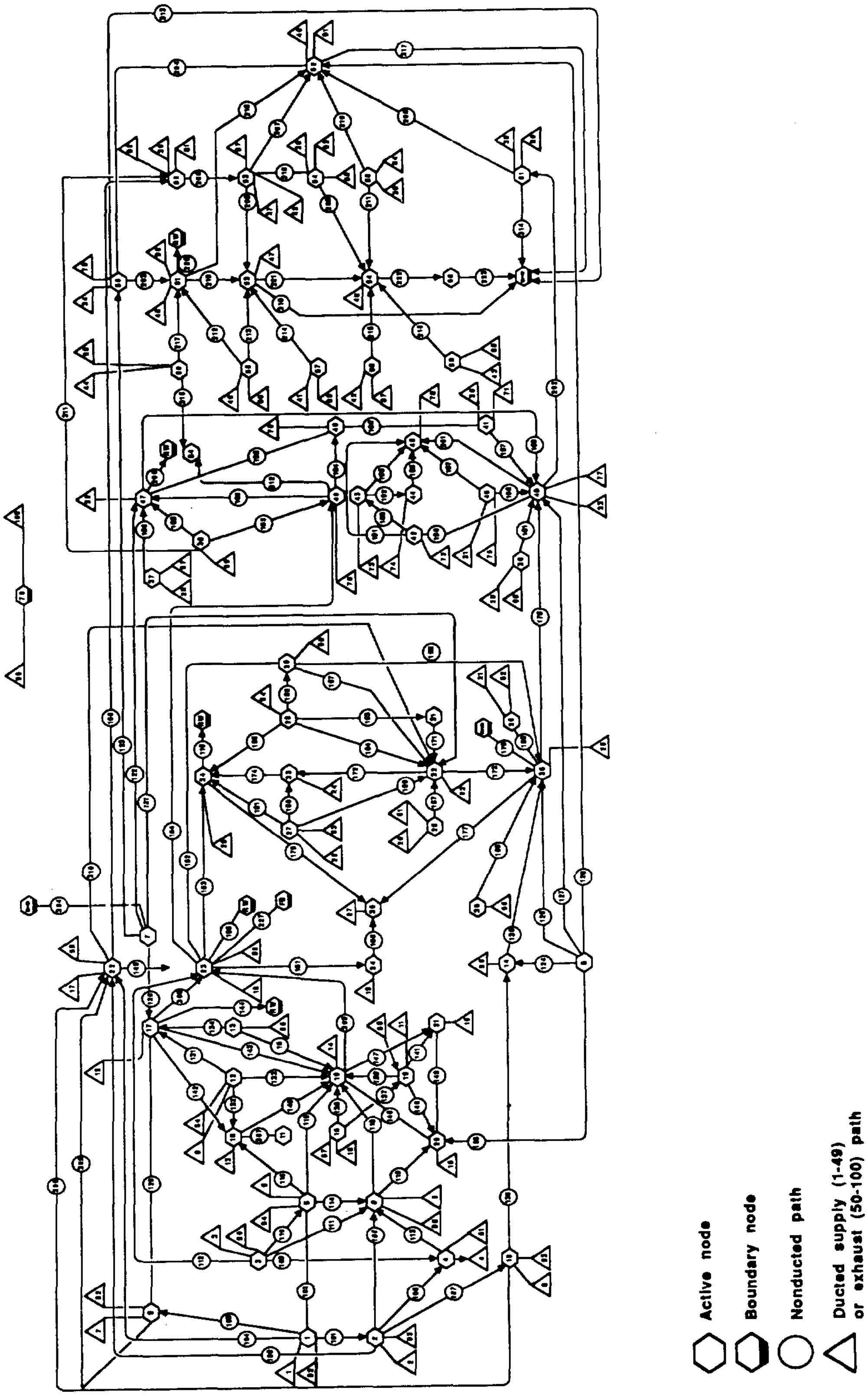
The model required 88 nodes to adequately represent auxiliary building areas. Fan curves representing flow rate versus head were utilized in the model for the auxiliary building supply and exhaust fans. This allowed the model to respond to changes in flow and pressure in a manner similar to the auxiliary building HVAC system. Three hundred twenty-seven flow paths were required to adequately represent the ducted and nonducted flows within the building. Nonducted flows, the primary mechanism for noble gas migration in the auxiliary building, occur through openings between adjacent areas such as nonsealed penetrations, doorways, hatchways, gratings, and stairwell openings. A favorable pressure gradient across these flow paths provides the means for gas migration. The nonducted portion of the auxiliary building flows required 143 paths.

Since no loop seals were used in the drains, the drain line system represents a network of paths between auxiliary building areas available for tracer gas migration. To model this migration mechanism of gas, 70 paths were required. Eight paths were required to allow for the release of tracer gas in the model at the source nodes.

The thermal-hydraulic code uses the Hardy-Cross loop balancing method to obtain unknown loop flows. This code is discussed in detail in the Appendix. One hundred loops describing the ducted flow paths, 59 loops describing the drain line network, 25 loops describing high-resistance, nonducted flow paths, and four loops describing tracer gas sources were required for this effort and were determined by inspection. Forty-three additional loops were required to describe the remaining auxiliary building nonducted flow paths and were determined by an automatic loop-generating algorithm.

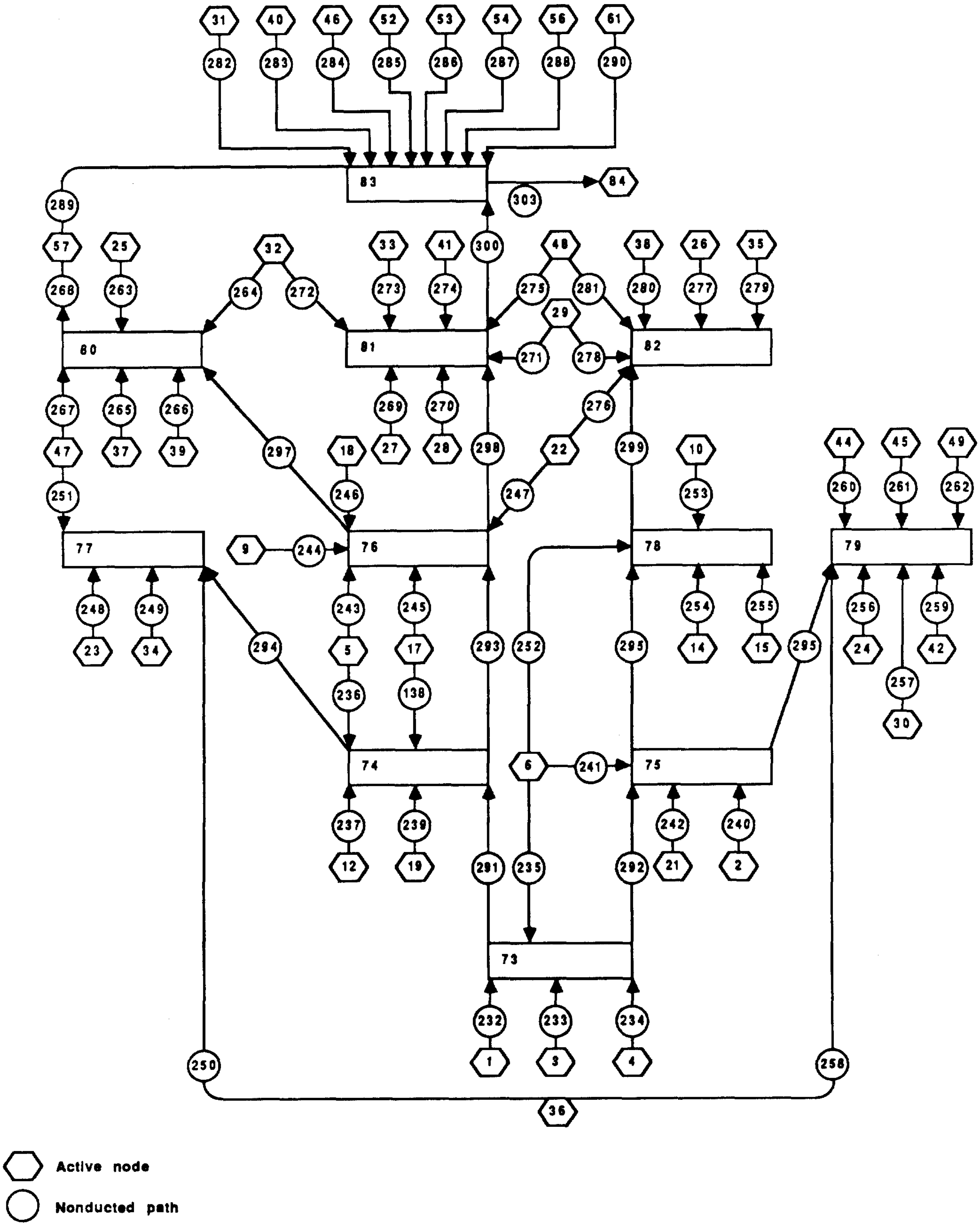
Before the model described above could be used to calculate tracer gas migration, a series of computer runs had to be made to determine a set of path flows and resistances that would produce pressures calculated by the code that were in agreement with the auxiliary building pressure measurements. This set of path flows and resistances was used as an initial estimate of auxiliary building values in the benchmark runs. The test and balance report HVAC system configuration was used for this series of runs.

The benchmark efforts were accomplished by releasing a tracer gas in nodes corresponding to the source locations of the tracer tests. Initially, all auxiliary building flows and resistances in the model were fixed at the estimated values determined in the



M2157.002 07-88

FIGURE 1
NODALIZATION SCHEMATIC FOR AUXILIARY BUILDING
NOBLE GAS MIGRATION STUDY



M2157.001 07-88

FIGURE 2
DRAIN LINE NODALIZATION SCHEMATIC

previously discussed series of computer runs. The code calculated the concentration of the tracer gases at all active nodes in the model. The concentration ratio was determined from these results by dividing the calculated concentration of an active node by the source node concentration. The calculated concentration ratios were then compared to the measured concentration ratios for corresponding plant locations. The initial estimates of nonducted path flow rates were then adjusted and the set of benchmark runs were made in an iterative process to achieve satisfactory agreement between the calculated and measured concentration results.

After completing the benchmark effort, the computer models were used to investigate the effects of potential plant changes on gas migration. A series of three runs, each for a different configuration, was performed.

The first run investigated the effects of rebalancing the auxiliary building HVAC system with the net supply and exhaust flows unchanged from the benchmark runs. The second run represents the design HVAC system configuration and the third run investigates the effects of adding a third exhaust fan in parallel with the existing exhaust fans. All three runs considered the effects of sealing problem penetrations, such as floor drains.

Discussion and Results

The measured pressures of the auxiliary building and the pressures calculated by the computer model for the benchmark runs are in good agreement. With few exceptions, the calculated pressures are within .005 inch of water of the measured pressures. Ducted flows used in the computer model are typically within 5% of the test and balance report measured flows.

Typically, the tracer gas concentration ratios calculated by the computer model for the benchmark runs are in order of magnitude agreement with the measurement of the tracer tests. The model is capable of being tuned to a finer degree to bring it into much closer agreement with the tracer test results; however, this was not done at this time. The calculated results for a few nodes do not agree with the measured results which indicated tracer gas migration against the associated pressure gradients. For these cases both the measured and calculated pressure gradients would prevent the propagation of the tracer gas. The direction of these pressure gradients both predicted and measured is also supported by the test and balance report results which show a net ducted exhaust from these nodes. One possible explanation for this behavior is that the fans used to mix the tracer gas in the source node forced the migration to adjacent areas. These fans are not normally present and were not present when the pressure measurements were made.

Similar anomalies occurred for two other nodes. Due to the physical layout of the plant in these areas, it is possible that a natural circulation loop exists causing the migration of the tracer gas. These areas consist of partial height block walls with open doorways and no ceilings. The mixing fans were also present in these nodes and could have induced these flows too.

To demonstrate the model's ability to predict gas migration and the effects of plant and system modification on migration, a portion of the tracer gas test concentration ratio results for the floor at the 120' elevation and the corresponding model predictions for the benchmark runs are shown in Table 1. These results consider a tracer gas source in node 44. Figure 3 is a node diagram showing the physical layout of this area of the plant.

The first run of the plant modification series was designed to investigate the effects of rebalancing parts of the HVAC system by adjusting some of the ducted flows. The HVAC system flow was adjusted for nodes 39, 40, 43, 44, 45, and 49. As a result of this rebalancing, the pressures of nodes with revised ducted flows and the pressures of some adjacent nodes changed as expected. The pressures of the remaining nodes were comparable to the pressures determined for the benchmark. The tracer gas concentrations seen in the benchmark runs were considerably changed by the rebalancing of the HVAC flows indicating that the migration pattern was also changed. The effect of these adjustments was to eliminate the predicted gas migration to node 45 and to reduce the predicted migration to nodes 42, 43, and 49. A subset of the concentration ratio results for this run is presented in Table 1.

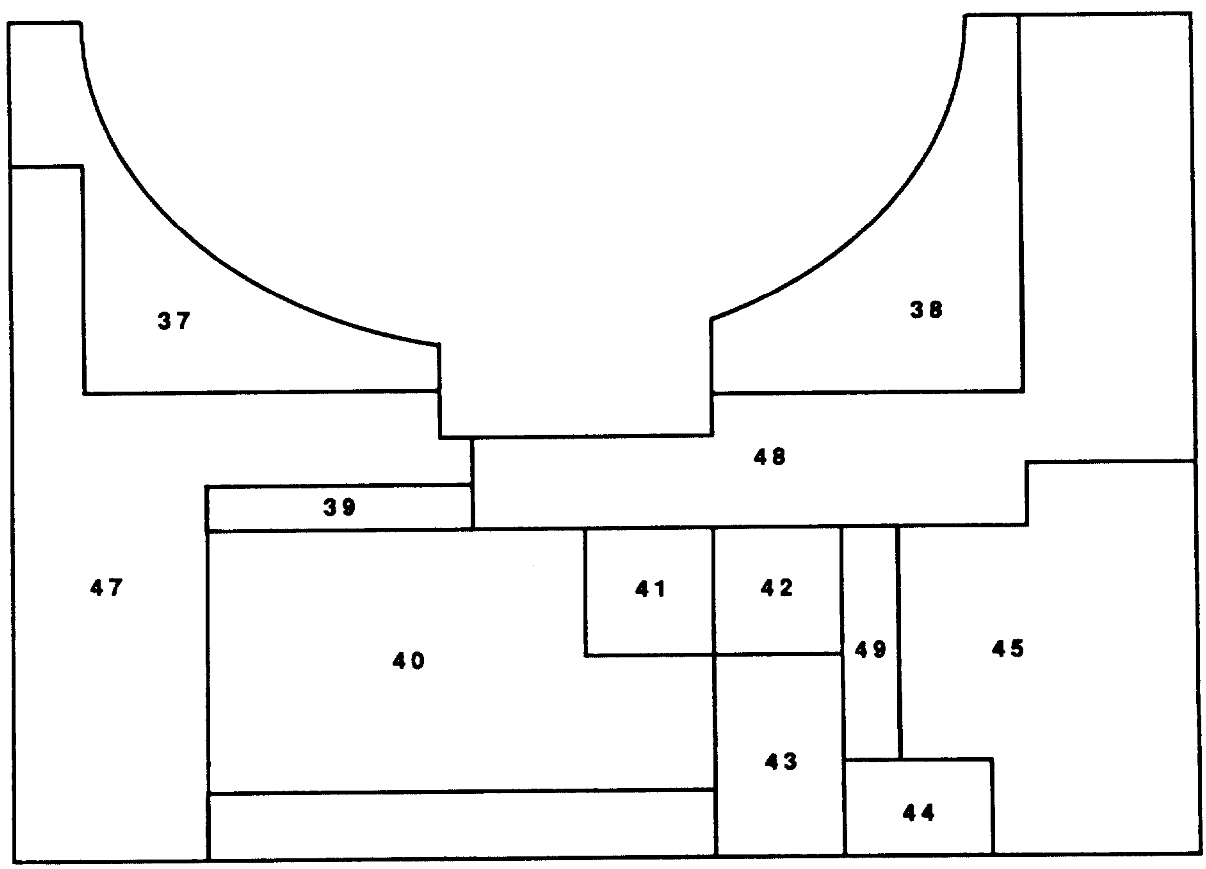


Figure 3: Node Diagram—120 ft Elevation

TABLE 1 - Tracer Gas Concentration Ratio Results
Concentration Ratio*

Node	Tracer Test	Benchmark Run	Run 1	Run 2	Run 3
37	--	0	0	0	0
38	--	0	0	0	0
39	--	0	0	0	0
40	--	0	0	0	0
41	--	0	0	0	0
42	--	.053	.043	.053	.051
43	--	.053	.043	.053	.051
44+	1	1	1	1	1
45	.00219	.00186	0	.00238	.00323
47	.0004	0	0	0	0
48	.004	0	0	0	0
49	.015	.054	.043	.053	.051

$$\text{*Concentration Ratio} = \frac{\text{Concentration of node i}}{\text{Concentration of source node}}$$

+Source node during tracer gas test is 44

The second run in the series was designed to investigate the flows and pressures in the auxiliary building for the design HVAC system configuration. This configuration was similar to the benchmark model with reduced net exhaust flow and the sealing of some nonducted paths. The behavior resulting from this run was similar to the benchmark runs. The auxiliary building node pressures determined were typically slightly higher than the corresponding pressures for the test and balance report configuration because of the reduced net exhaust from the building. The model for the auxiliary building exhaust fan shifted to a different point on the fan curve to adjust for the effective increase in system resistance. The tracer gas migrations determined for this run were similar to the benchmark results for the same sources as partially shown in Table 1.

The goal of the final run in the series was to determine the effects of increasing the auxiliary building exhaust capacity by 50%. This was accomplished by adding a third exhaust fan in parallel with the two existing exhaust fans. The model predicted lower pressures for the auxiliary building nodes brought about by the increased net exhaust from the auxiliary building. Although the building is at a more negative pressure, the direction of pressure gradients between nodes was not changed since the additional exhaust was split proportionately between the nodes by the model. The tracer gas migrations determined for this run are similar to those obtained for the benchmark runs for the same sources. A subset of these results for a node 44 tracer gas source is shown in Table 1.

The model showed that the addition of the third exhaust fan did not increase the net exhaust from the auxiliary building by 50%. The lower auxiliary building pressures required the fans to develop more head, therefore, limiting the increase in net exhaust.

Conclusions

The analytical approach to the noble gas migration problem has proven to be a valuable asset. The benchmarked model showed itself capable of analyzing and assessing the effects of both major and minor changes in the "system." Without requiring a major testing effort, this model assists in assessing the effects of rebalancing the HVAC system and sealing drains and doors, for example. It also facilitates the processing of major modifications such as the addition of another exhaust fan even before any major design effort is started.

The analytical model can be updated to reflect any changes in the plant physical configuration and can provide an economical means of assessing their affect on the HVAC system and the potential for noble gas migration.

The analytical approach, even though it requires some experimental data for benchmarking, requires considerably less experimental verification of HVAC system performance than actual modifications.

The analytical approach is a valuable tool to use in solving problems such as noble gas migration and HVAC balancing.

Appendix (2)

Thermal-Hydraulic Computer Code

In order to describe the transportation of system fluids and heat, solutions of mass, momentum, and energy balances are obtained by employing a computer code. Incompressible and compressible behavior is considered. A thermal-hydraulic computer code has been developed to treat the migration of noble gases. This code uses a general node-path formulation accommodating a steady-state analysis.

Pressure, temperature, and fluid composition are accounted for, or are specified, at the nodes. The code offers a menu consisting of boundary and active node types. For a boundary node, the temperature of a solid material or the temperature, pressure, and composition of a fluid are user-specified. For an active node, the solid material temperature or fluid properties are all calculated.

The duct friction loss formulation will accommodate not only turbulent flow devices and laminar flow devices but also devices operating in the region in between these limiting causes. The generalized pressure loss relation used is derived from Coad and Sutherlin[3]:

$$P_u - P_d = \frac{RW^E}{2g_cP_u}$$

where:

P_u = path upstream node pressure (psfg) [Pa]

P_d = path downstream node pressure (psfg) [Pa]

R = path "resistance parameter" value (a value greater than zero is required) (The units of R depend on the value of E.)

W = path mass flow rate (lbm/h) [Kg/h]

E = path mass flow rate exponent (dimensionless)
= 2.0 for turbulent flow

g_c = gravitational constant (ft/h^2) [m/h^2]

P_u = path upstream node density (lbm/ft^3) [kg/m^3]

In this formulation, the path resistance parameter value depends upon the flow rate exponent value assigned. In the case of turbulent flow, R is the conventional loss coefficient divided by the square of the associated flow cross-sectional area.

To represent a fan, the recommended path type permits direct input of fan total head rise in feet of fluid flowing as a function of fan inlet volume flow rate. Since the typical fan manufacturer's curve (for fixed rpm and fixed blade angle) plots pressure rise versus fan inlet volume flow for a stated value of fan inlet density, it is necessary to convert this density-specific data to the more general form required by converting the pressure rise scale to a head rise scale using the inlet density. This curve must be examined to ensure that head rise decreases monotonically with increasing volume flow. If this does not occur, there is an unstable region in the fan curve that must be eliminated. Such a region is replaced with a connected line segment having a slope of the proper sign and sufficient magnitude for stability.

To aid in the modeling of heat generation and heat transfer effects, additional node and path types are provided along with a menu of heat transfer function types. Heat transfer between a pair of nodes may be accounted for by a convective or radiative type of path. This type of path may connect any selected pair of nodes and one of several heat transfer function types may be assigned to it. The heat flow rate through such a path is taken as the product of the path area, the temperature difference between the path and nodes, and the value of a heat transfer coefficient function. Available are heat transfer function types suitable for representing the following:

1. forced convection to a body immersed in a fluid stream, or to the walls of a channel,

2. natural convection to the side walls, floor, or ceiling of a room, or to a body exposed to the room's atmosphere, and

3. radiation between solid surfaces, or between a surface and an adjacent atmosphere.

The menu of node and path types provided by the code allows for the proper modeling of heat sources, temperatures, compositions, and densities.

Methods of Solution Used by the Thermal-Hydraulic Computer Code

The steady-state version of the code employs an iterative process to obtain a solution. First, the full set of unknowns is divided into four subsets:

1. compressible fluid system loop flows,

2. densities of compressible fluid system active nodes,

3. specie concentrations of compressible fluid system active nodes, and

4. temperatures of all active nodes.

Then, in rotation, each subset is solved via Newtonian or Gaussian iteration until successive solutions differ by no more than a user-specified tolerance. Finally, when successive solutions of all four subsets require no more than one iteration per subset (to meet the tolerance criterions), it is assumed that a solution has been found. The compressible fluid system loop flows are the set of unknowns recommended by Cross(4) for the solution of a flow network. Modern treatment of this method refers to it as the loop balancing method(5). Cross also presented a node balancing scheme that is simpler than the loop balancing method since it avoids setting up the flow loops. However, the node balancing scheme exhibited numeric difficulty in some cases. No such trouble has occurred with the loop balancing method. In some cases, a proper set of loops may be determined by inspection of the flow diagram for a network. However, for the more complicated cases, an automatic loop-generating algorithm, similar to that described by Epp and Fowler(6), is used.

References

1. Lagus, P. L. et al., "Tracer Gas Testing Within the Palo Verde Nuclear Generating Station Unit 3 Auxiliary Building," 20th DOE/NRC Nuclear Air Cleaning Conference, August (1988).

2. Pascal, W. B., Curry, R., and Hammersley, R. J., "HVAC Integrated Systems Analysis," ASHRAE Transactions, V. 93, Pt. 2 (1987).

3. Coad, W. J. and Sutherlin, P. D., "A new look at fan system curves," Heating/Piping/Air Conditioning, pp. 47-51, November (1974).

4. Cross, Hardy, "Analysis of flow in networks of conduits or conductors," University of Illinois Bulletin 286, November (1936).

5. Streeter, V. L., and Wylie, E. B., Fluid Mechanics, McGraw-Hill Book Company, New York, 6th ed., 1975.

6. Epp, R., and Fowler, A. G., "Efficient code for steady-state flows in networks," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 96, No. HY1 (1970).

DISCUSSION

KUGLER: I want to ask if your analytical model has any allowance for buoyancy terms to take account of thermal gradients or thermal differences?

ADAMS: We have that feature but it is not utilized in this problem. It was done as a pancake model, all on the same level, but we do have pressure density differences as a function of elevation included in the model.

WOODS: I just wanted to make the statement that we used the results of both the tracer testing and the computer model to implement our plant changes and to identify some non-duct airflow bypasses that are now in the process of being sealed. As was mentioned earlier, it is a regulatory nightmare to get changes made so it has taken awhile to get it done. We are still in the process of getting the changes implemented. It was a very interesting paper and an innovative approach. The annulus is one of the worst actors in the heat load. I am sure anyone who has worked on a BWR has had similar problems. I think every BWR in the nation; and maybe in the world, has these problems.

CONTAINMENT COOLING:

IMPROVED COOLING COIL EFFECTIVENESS

August Kugler
Kaiser Engineers, Inc.
Oakland, California

Abstract

Containment cooling systems for the Boiling Water Reactor (BWR) have occasionally been undersized and the capacity not suitably proportioned with elevation, resulting in excessively high containment temperatures.

The conventional design solution recommended has been to increase the ventilation capacity and to duct additional ventilation air to the locations of elevated temperature. Due to space limitations, ducting can be difficult to locate in the BWR containment. Additional air flow into select areas can also increase the containment heat load by increasing heat transfer mechanisms, further taxing the overall containment heat removal capacity.

Studies were performed during construction of the WNP-2 Plant to evaluate methods of increasing sacrificial shield wall temperatures, which led to consideration of reversing the direction of air flow in the annulus between the reactor pressure vessel (RPV) insulation and the sacrificial shield wall (SSW). This construction design change was not required.

The concept was, however, evaluated and tested during power ascension testing to alleviate excessive temperatures in the upper containment. Test results were very decisive; peak temperatures in the upper containment were reduced by as much as 26°F (15°C).

Design changes were implemented to incorporate this concept into the containment cooling configuration, providing an effective solution to a perplexing problem.

Designers of containment cooling systems should consider reversing ventilation flow in the annulus between the reactor pressure vessel insulation and the sacrificial shield wall to reduce temperatures at the top of the BWR containment.

Engineers who are resolving local, high-temperature areas in primary containment should consider ducting air from local hot spots directly to cooling coils to increase the temperature differential across the cooling coil (improving heat removal capacity) and to short circuit the high-temperature air to cooling units, thereby limiting containment areas affected.

Introduction

Technical specifications for WNP-2 (an 1100 MWe BWR) limit the average primary containment atmospheric temperature to 135°F (57°C) and the maximum temperature to 150°F (66°C) in local areas where safety-related equipment has been installed.

WNP-2 experienced high environmental temperatures in primary containment during the early phases of power ascension testing. The temperature in the bulkhead region near the top of the primary containment reached 69°C. The design basis heat load for containment cooling was 3.3 x 10^6 Btu/hour, while the as-designed containment cooling capacity was 6 x 10^6 Btu/hour.

Figure 1 illustrates the containment cooling system and the anticipated heat loads by zone.

Evaluation and Rework

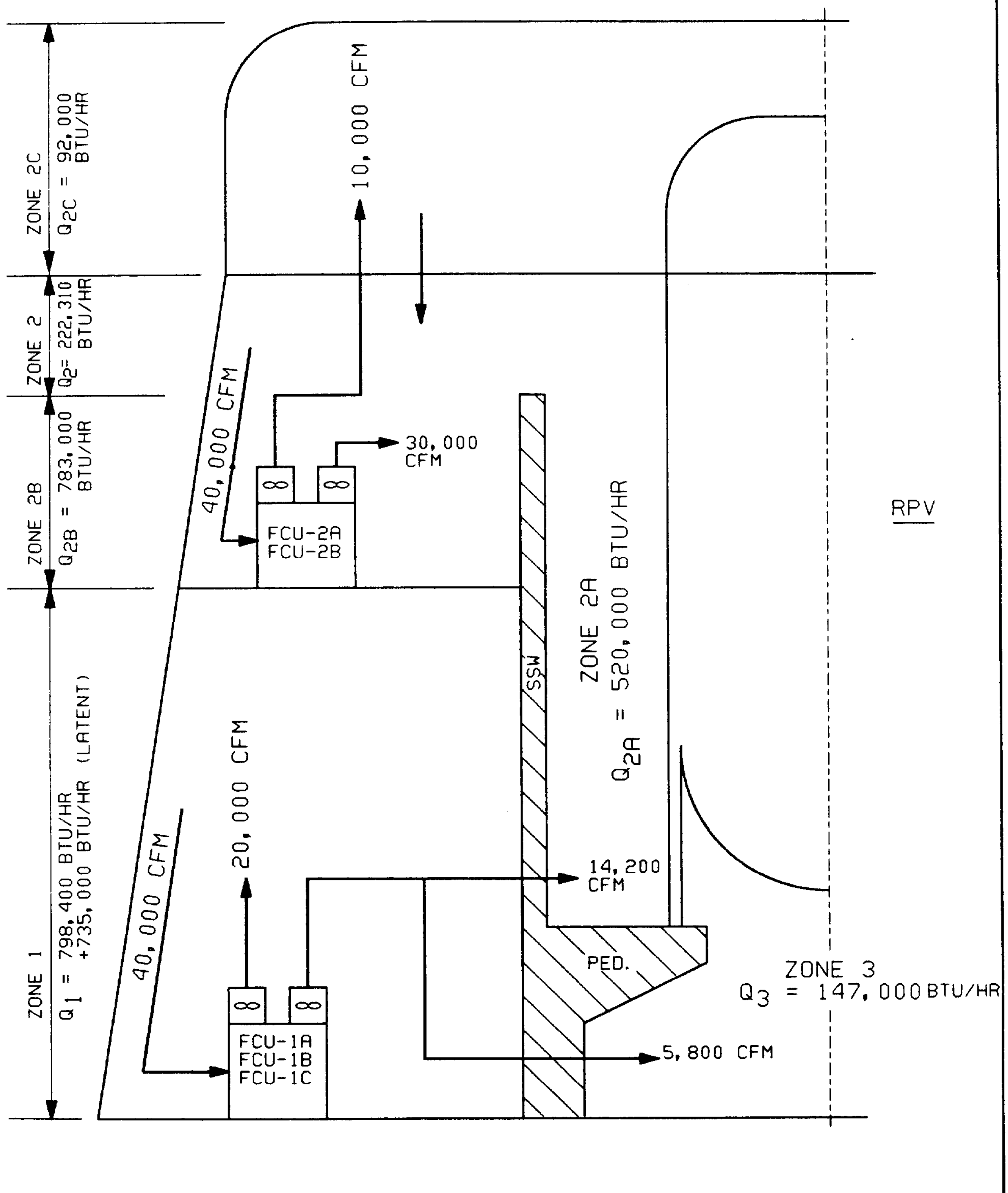
Instrumentation was not sufficient for accurate assessment of primary containment heat loads by zone or by individual cooling unit. Early estimates of heat loads were, however, in excess of 10 million Btu/hr.

Early work involved reducing heat load. Inspections were made "at temperature" to locate missing insulation and to locate hot spots indicative of degraded insulation performance. Inspections included use of infrared temperature detectors. These inspections identified insulation missing at reactor pressure vessel nozzles, on piping including feedwater piping, at pipe whip restraints and reactor pressure vessel stabilizers. In addition, high-temperature air streams approaching 200°F (93°C) were emanating from openings in Reactor Pressure Vessel (RPV) insulation at the top of the Sacrificial Shield Wall (SSW).

Insulation rework reduced the Primary Containment (PC) heat load to less than 6 million Btu/hr; however, the two fan coil units at the higher elevation were still removing 75% of the PC heat load. Projections to more adverse operating conditions (higher power levels or cooling unit malfunction) indicated unacceptable temperature conditions would develop.

The possibility of reversing air flow in the annulus between the RPV insulation of the SSW emerged during the evaluation of redesign alternatives. This alternative was particularly attractive because there was limited space available for installation of ducting from the lower cooling units to the top of containment. Furthermore, ventilation flow up the annulus appeared to be pressurizing the RPV/insulation annulus, forcing high-temperature air streams out into the top of the PC. Additionally, the Nuclear Steam Supply System (NSSS) contractor specified a minimum temperature of 80°F for air impingement on the RPV skirt, precluding future reductions in cooling water temperatures to enhance heat removal capacities.

FIGURE 1
PRIMARY CONTAINMENT - DESIGN BASIS HEAT LOAD



This approach would also transfer the RPV insulation heat load to the lower fan coil units (FCUs), increasing effective heat removal capacity with no penalty to average PC temperature. As much as 1.5 million Btu/hr would be transferred to the lower FCU's, reducing the heat load on the upper two cooling units.

The Special Test

A special test was performed during hot shut-down conditions to confirm the viability of the design approach. One million Btu/hr were transferred from the upper cooling units to the lower cooling units, and temperatures at the top of the primary containment were reduced by 14°F (8°C) to 26°F (14°C). Figure 2 illustrates the locations of temperature indicators, and Table 1 provides test results. Based upon the success of the special test, design modifications were prepared and implemented.

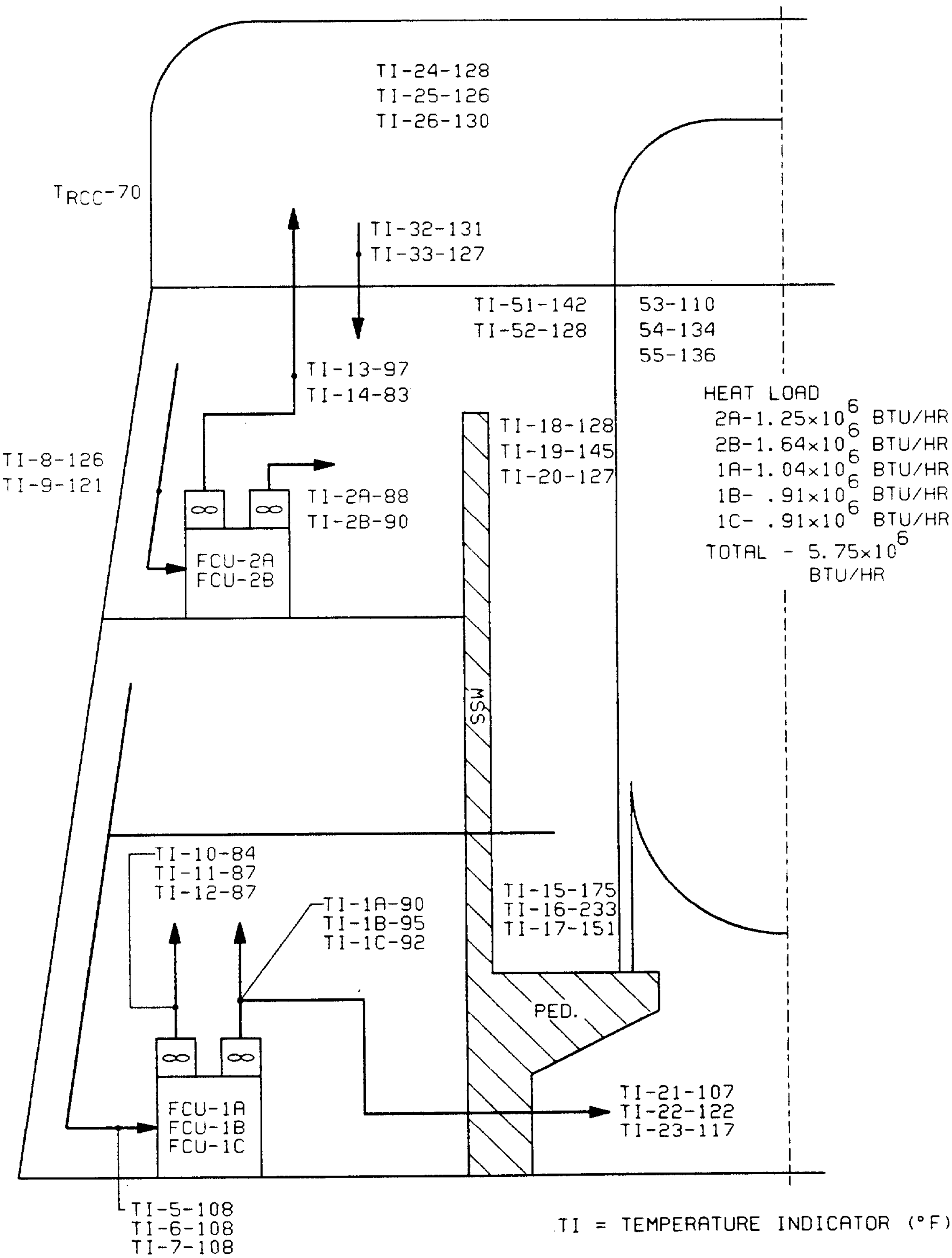
Additional Redesign

The temperature of the water supplied to the primary containment cooling units was subsequently reduced by an equally innovative redesign prepared by utility design engineers.

Recommendations

- There are significant advantages to using the RPV/SSW annulus as a return duct to, rather than a supply duct from, primary containment cooling units.
- Short circuiting high-temperature, localized air streams to cooling unit return ducts may be preferable to ducting more ventilation supply to localized hot spots.
- Heat loads of 6 million Btu/hr are more realistic than 3 million Btu/hr for the primary containment of an 1100 MWe BWR with reflective piping and RPV insulation.
- Buoyancy effects and high elevation stratification must be considered in primary containment ventilation designs.
- Adequate water side and air side instrumentation is necessary to evaluate primary containment heat loads and cooling unit performance.
- Precautions to protect primary containment cooling units from the accumulation of debris and from baffle damage during construction are recommended.

FIGURE 2
PRIMARY CONTAINMENT HEAT LOAD
OCTOBER 1984 DATA



TI = TEMPERATURE INDICATOR (°F)

Table 1. June 1984 Test Summary

Bulkhead

	Normal	Reverse
TI-51	147	133
52	125	110
53	125	107
54	156	130
55	---	---

Head Region

	Normal	Reverse
TI-24	101	108
25	87	95
26	105	107
32	102	101
33	100	98

Upper FCUs

	Normal	Reverse
TI- 8	121	108
9	110	95
13	80	79
14	---	---
2A	78	75
2B	71	71
Q2A	$1.86X10^6$	$1.43X10^6$
Q2B	$1.68X10^6$	$1.04x10^6$

Lower FCUs

	Normal	Reverse
TI- 5	---	95
6	---	90
7	---	70
10	---	90
11	---	89
12	---	71
1A	---	117
1B	---	144
1C		76
Q1A		$.4X10^6$
Q1B		$.78X10^6$
Q1C		--

SSW Annulus

	Normal	Reverse
TI-15	78	148
16	76	112
17	76	120
18	90	112
19	95	126
20	87	127

TI - temperature indicator in °F
Q - energy transfer rate in Btu/hr

Acknowledgments

WNP-2 Technical Staff and Design Engineers

References

1. Design Engineering Status Report on WNP-2 Containment Cooling, prepared by W. G. Conn and A. N. Kugler, December 4, 1984.

DISCUSSION

ORNBERG: Please clarify the location of supply and return ducts. If there are any ring headers for supply and return, where are they located?

KUGLER: The return ducts were located around the containment As I recall, the return duct headers were located at the lower elevations in containments. Now, I said the reduction in elevation here (return ducts) was a few feet, but it was 30 feet. There was no compensating action taken for that construction design change and I believe that is the major source of the problem. I believe the elevation of these lower fan coil units should be around 450-460 feet (elevation) and this is 501 (elevation). You can see that if I had my suction ducts up high enough, I would be taking a heat load from this area (501 elevation). The main heat load is high in containment. It is a little unrealistic to think that all steam leaks will be low in containment when the steam pipes are up high in containment. As far as providing cooling coils for the highest temperature air in a containment, I know where that is. On a BWR it is right up top.

The author has asked Dennis Myer of the WPPSS Engineering Management staff to forward copies of the WNP-2 primary containment ducting layout drawings to Dr. Melvin First. Mr. Myer may be reached at 509-337-2501 at WNP-2 in Richland, Washington.

ORNBERG: We found that you get good mixture by having good distribution on the supply end but then you have to draw heat back down to the units. Sometimes, simple return ducts and suction points do not have any effect because they have a limited area of influence.

HVAC PERFORMANCE MONITORING IN A HIGH TEMPERATURE ENVIRONMENT

D. J. Benton, P.E.
Sargent & Lundy

L. J. Corts
Commonwealth Edison Company

Chicago, Illinois

Abstract

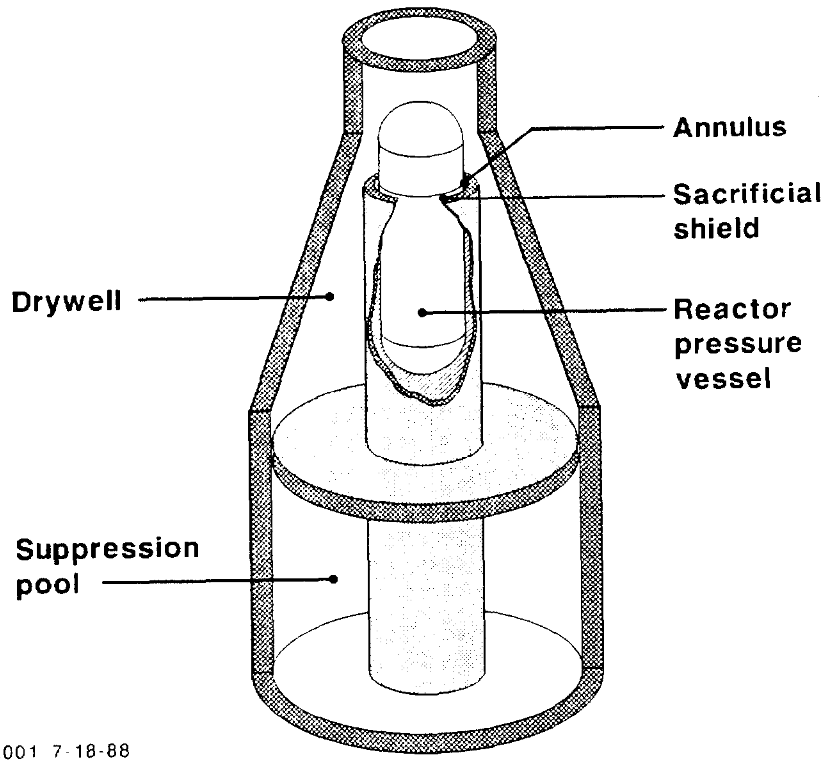
This is a discussion of temperature monitoring in a boiling water reactor (BWR) drywell. The monitoring program is used to determine HVAC operating temperatures and their impact on the operating life of electrical equipment. If high temperatures are discovered, the HVAC system operation is revised, minor modifications and repairs are implemented, and any major modification is designed to lower operating temperatures.

The effectiveness of the monitoring program is examined. Two high-temperature events evaluated by the program, and an event that was not discovered by the monitoring program, are reviewed. In conclusion, monitoring system design is considered.

Introduction

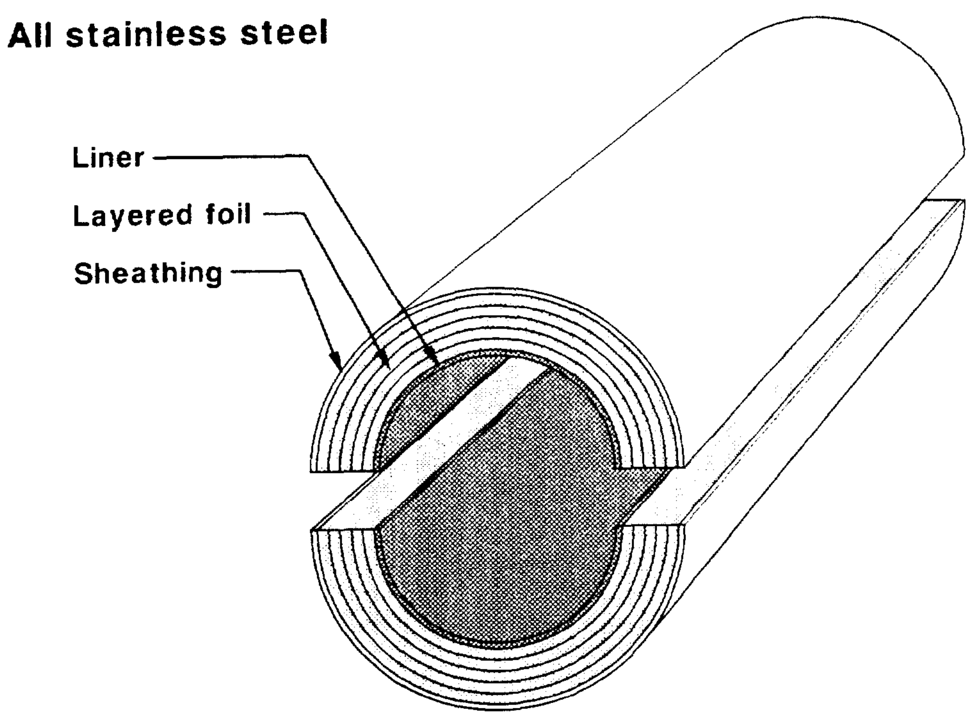
La Salle County Station is one of six dual-reactor stations in the Commonwealth Edison Company network that serves Chicago and the northern quarter of Illinois. The station utilizes single-cycle forced-circulation BWRs, each rated at 3273 megawatts thermal (MWt), with a gross electric output of 1122 megawatts electric (MWe). The containment design employs a BWR Mark II concept of over-under pressure suppression, with the suppression pool located immediately below the drywell (see Figure 1). In the drywell, the nuclear reactor boils water at 550°F and is the heart of the station. It also includes the piping systems that carry water to protect the reactor and distribute the energy to the station.

At peak operating conditions, 17 billion Btu/hr is sent through the main steamlines toward the turbine. Supporting systems inside the drywell include the safety relief lines, reactor recirculation, residual, and emergency core cooling. These systems have piping that may be hot during normal operation. Hot piping is insulated with metal reflective insulation, composed of rigid, cylindrical-shaped sections of layered stainless steel (see Figure 2). The layers reflect heat back into the pipe and reduce the heat transfer to the space. A pipe with 3 inches of insulation will transfer less than 10% of the heat of an uninsulated pipe.



C1686R.001 7-18-88

FIGURE 1
PRIMARY CONTAINMENT



C1686R.002 7-18-88

FIGURE 2
METAL REFLECTIVE INSULATION

The drywell air temperature is controlled during normal operation by the drywell cooling system. The system consists of two main fan coolers and ductwork (see Figure 3). The coolers, which may be operated individually or together, are located in the lower elevations of the drywell. Air is drawn into the cooler from the lower elevations of the drywell and passed over chilled water coils. The 60°F supply air is distributed throughout the drywell via the ductwork system. The design criterion is to maintain average temperature in the drywell below 135°F. This temperature is an input to the loss-of-coolant accident analysis.

Temperatures are monitored using the drywell temperature monitoring program. Resistance temperature devices (RTD) located throughout the drywell are monitored from the main control room. Supplemental thermocouples that are monitored using a local recorder are located just outside the drywell. The evaluation of data occurs on a quarterly, weekly, or as-needed basis in accordance with program requirements.

The primary containment cooling system takes heat from the drywell. Chilled water at 46°F is supplied to the fan coolers, where it cools the air and is then returned to the primary containment chillers. These chillers reject approximately 8 million Btu/hr to the 2058-acre La Salle Lake in the summer. In the winter, the heat is rejected to the station heat recovery system which ultimately uses the heat to warm outside air entering the station. This drywell heat offsets 2400 kW of electric heat.

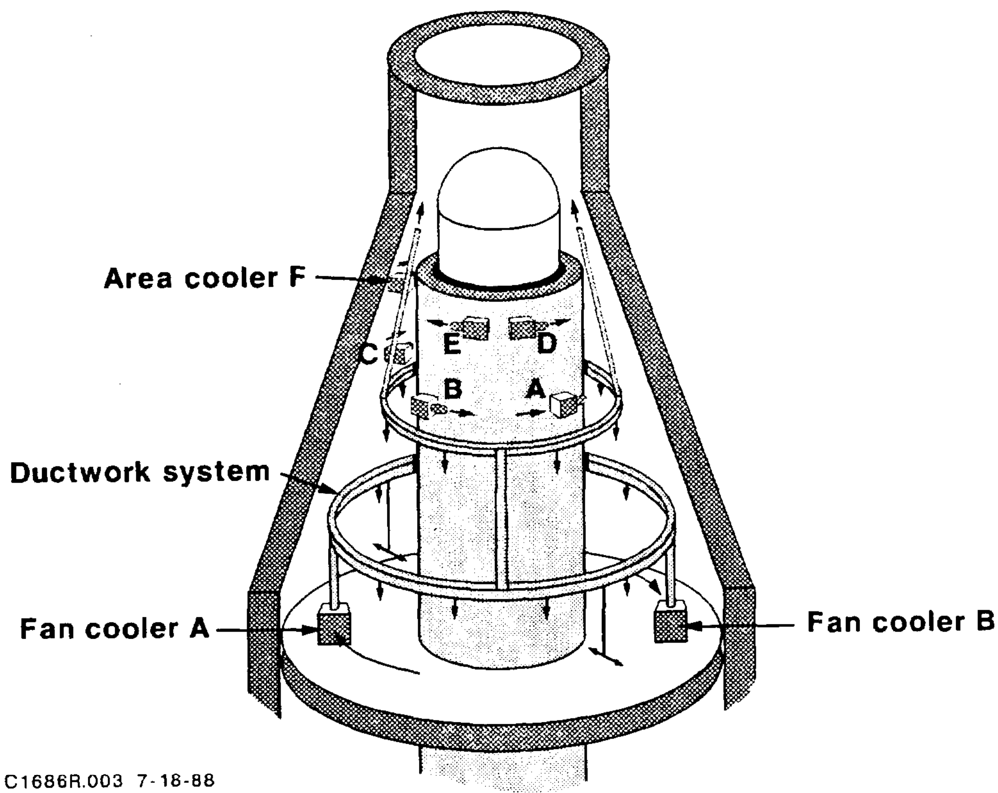


FIGURE 3
DRYWELL COOLING SYSTEM

Initial Operation

The license to begin operation of Unit 1 was issued in April 1982. When the reactor vessel and piping were first brought to operating temperature, the drywell became excessively warm, thereby negatively impacting the operating life of electrical equipment. The causes of the high temperatures and potential resolution of the problem were evaluated.

High temperatures were not unexpected since many other stations had experienced difficulty in maintaining proper drywell/containment temperature. This was documented in EPRI report NP2694, which states, "that a majority of commercial nuclear power stations in the United States have experienced higher than expected containment air temperatures."(1)

At initial operation, the actual heat load was found to be approximately 7 million Btu/hr sensible which was considerably greater than the 4.17 million Btu/hr design. For the drywell cooling system to remove this much heat, either the average temperature of the drywell would have to be increased or the capacity of the drywell cooling system would need to be increased. Increased air temperatures are not acceptable because the accident analysis would have to be redone, which would be an expensive and time-consuming effort.

As an immediate and short-term resolution to the problem, cooling equipment that was originally designated as standby was then brought into full-time service. Both fan coolers were put into continuous operation, thereby eliminating redundancy. In addition, the station began a major drywell cooling modification in order to increase the drywell cooling system capacity by installing additional fan coolers and water chillers.

However, continued hot operational testing showed that the high temperature problem was not satisfactorily resolved. The air near electrical equipment, which was mounted on the piping, became excessively warm, causing the operating life to be shortened. In order to provide the cooling where it was most needed--near electrical components--approximately a dozen minor modifications to the drywell cooling system were implemented.

Insulation was added at the reactor vessel and other major heat loads. Temperature sensors located above the annulus region between the reactor vessel and the sacrificial shield had evidenced temperatures in excess of 200°F. Added insulation, at the annulus, served the dual purpose of reducing the heat transfer coefficient and restricting the airflow. To increase the total airflow of the drywell cooling system, two minor modifications were made. The fan cooler housings were redesigned to increase the inlet area. In addition, the fan blades were adjusted to use the full brake horsepower available from the motor.

It was soon recognized that some areas of the drywell were more critical than others because of the impact on sensitive electrical equipment. The 18 safety/relief valves (SRVs) located in the middle elevations and the four main steam isolation valves (MSIVs) located in the lower elevations of the drywell had critical limit switches and solenoids. As a result, these two critical areas were chosen to receive more airflow. Minor modifications for these areas consisted of moving and/or adding ductwork registers.

Interim Operation

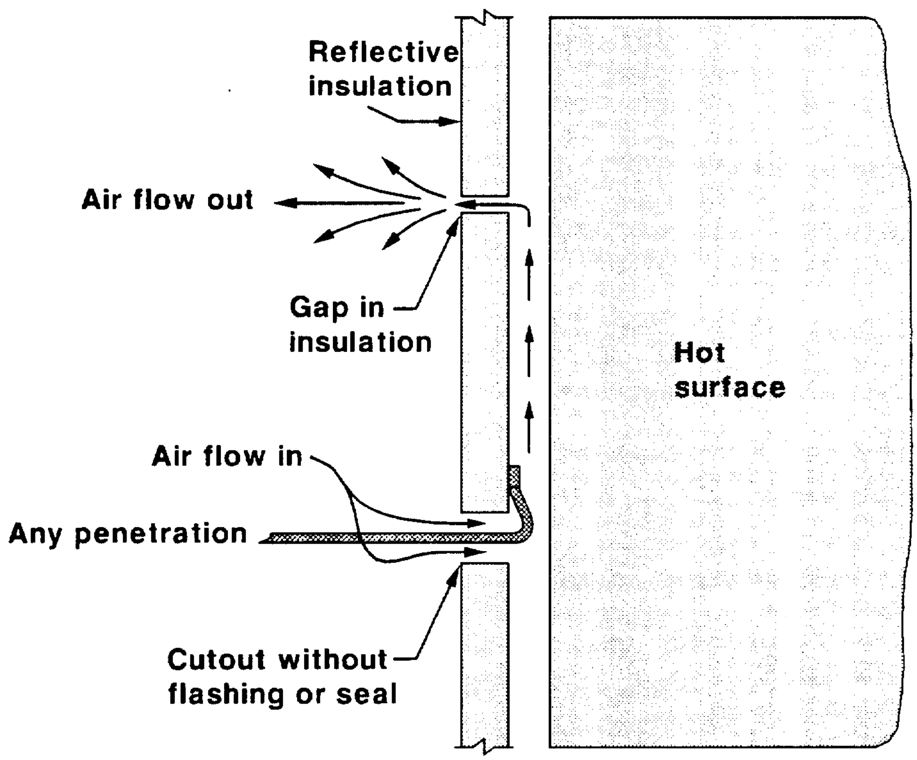
The reactor was brought to full power and run for approximately 1 year. In November 1983, when the unit was shut down for the first refueling outage and normal maintenance, it was discovered that some electrical cables in the upper elevations of the drywell had brittle and crumbling jacketing. An evaluation determined that the temperatures were probably in excess of 300°F in local areas.

A complete inspection was undertaken, resulting in the decision to replace the cables in approximately the upper one-third of the drywell. This was accomplished in approximately 2 months. Mechanical pipe snubbers were inspected and found to be locked in position. The mechanical snubbers have lubricating grease that solidifies after temperatures have exceeded approximately 300°F. The snubbers in the upper drywell were replaced. Other short-term solutions were to repair thermal insulation defects and provide additional ductwork to bring cooler air into the upper drywell.

It became imperative to ensure the thermal insulation system was the best possible. A detailed inspection of the insulation was conducted. Two major categories of problems--gaps between insulation and crushed insulation--were identified.

Gaps over 1/8 inch allow significant local airflow that carries heat (see Figure 4). Gaps may result from improper initial installation or from accidental damage due to people working in the vicinity. For example, insulation is held in place using buckles. These could be rubbed against and either left open, or worse yet, permanently deformed. The insulation can be crushed to approximately one-third its thickness and still maintain its heat transfer characteristics. However, a likely secondary impact of crushing is the creation of gaps, which must be separately considered. Ribbed pieces can be used to reduce crushing. As an alternative, galleries can be built so that it is not necessary for people to walk or climb on the pipes and insulation.

It was calculated that repair of the insulation would help the SRV area only marginally, and that it would be necessary to provide additional cool supply air to the area. The most extensive of the minor modifications was the installation of four ducts from the lower ring header to the upper elevations. Since the station had already been operating, it was determined the future space requirements for other modifications in the drywell should be minimal. Therefore, it was decided that the ducts could be run wherever



C1686R.004 7-18-88

FIGURE 4
EFFECT OF GAP OR CUTOUT REFLECTIVE INSULATION

space was available (access space to equipment had to remain). Calculations showed the use of these ducts would increase the airflow to the upper elevations by approximately 15%. This was estimated to be acceptable for continued plant operation. However, the major modification to add fan coolers was still required.

Since it would be several years before the drywell cooling modification was completed, an interim temperature monitoring program was developed to provide a mechanism for monitoring the local drywell temperatures. The monitoring program would also be used to determine the acceptance of the modification.

Interim Temperature Monitoring

The La Salle drywell temperature monitoring program was designed to augment the original drywell temperature monitoring system. The original system had been designed to measure representative area temperature throughout the drywell so that the average temperature could be determined and monitored. Technical specifications require that if the drywell average temperature exceeds 135°F, the problem must be corrected within 12 hours or the reactor must be shut down. Augmented monitoring was designed for the following purposes:

- To evaluate the effectiveness of minor modifications and repairs; the evaluation of initial operation had found that the temperature profile was more complex than that for which it had originally been designed.
- To evaluate actual degradation rates for drywell cabling and equipment; it was imperative to verify that the cabling would not again be damaged to the extent it had been during initial operation.
- To provide volumetric thermal data inputs for the long range modification; it was important to design the airflow distribution for the new area coolers.

To accomplish these objectives, the location and quantity of sensors had to be determined, and the new data needed to be evaluated.

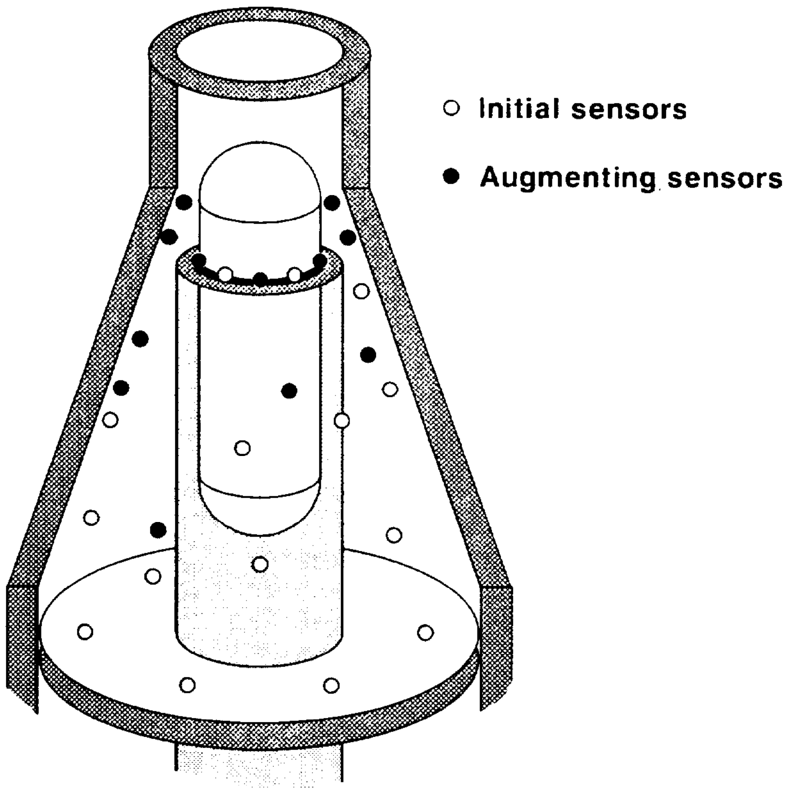
The original system consisted of 26 RTDs located throughout the drywell (see Figure 5). Sensors were located as follows:

Location	Quantity
Control rod drive	6
Annulus outlet	3
Top four elevations	12 (3 each elev.)
Lowest elevation	5
	26

The interim evaluation identified that the MSIV, SRV, and upper areas needed additional monitoring. Thirty-four thermocouple cables were strung throughout the drywell. The sensors were located as follows:

Location	Quantity
Head area	1
Upper elevation areas	12
Upper elevation valves	6
Annulus outlet	3
Middle elevations	2
SRVs	5
Lowest elevation	1
MSIVs	2
Inside ductwork	2
	34

The total of 60 temperature sensors would be used to monitor drywell temperatures. Based on the startup test data, a correlation matrix was developed to relate specific equipment to specific temperature sensors that would indicate representative local temperatures (see Figure 6). Temperature sensors not included in the matrix were left in place for future use.



C1686R.005 7-18-88

FIGURE 5
TEMPERATURE SENSOR LOCATIONS

Sensor	SRV Solenoids	SRV Limit Switches	MSIV Solenoids	MSIV Limit Switches	Cabling
ITE-VP205	170*	170	- -	- -	- -
ITE-VP206	170	170	- -	- -	183
ITE-VP207	170	170	- -	- -	- -
ITE-VP208	170	170	- -	- -	- -
ITE-VP209	170	170	- -	- -	183
ITE-VP210	170	170	- -	- -	- -
ITE-VP211	- -	- -	150	150	- -

* Temperature setpoint. If exceeded, evaluation of impact on EQ life is required.

C1686R.006 7-18-88

FIGURE 6
TEMPERATURE CORRELATION MATRIX

The operating life of electrical equipment can be expressed as a function of temperature and equipment-unique constants. For all critical electrical equipment, the operating life--environmental qualification (EQ) life--had been determined prior to installation based on laboratory testing. Using the correlation matrix, the EQ life was calculated at a temperature slightly higher than the normal operating temperature, and associated temperature sensor setpoints were assigned. The program established that if the measured temperature exceeded this setpoint, engineering evaluation of the impact on EQ life would be conducted. This evaluation would establish the probable cause of the excessive temperature, what corrective action was required, and when corrective action needed to be implemented.

High Temperature Events

The La Salle drywell temperature monitoring program was initiated in October 1985, and has been functioning continuously since that time. It has been an essential tool in diagnosing such events as a steam leak of a valve bonnet in 1986 and the failure of a cooling fan in March 1987. However, the program did not anticipate the failure of the linear voltage differential transformers (LVDT) on the reactor recirculating pump flow control valves.

Valve Bonnet Steam Leak

In October 1986, the Unit 1 temperature at sensor ITE-VP211, located on an MSIV, jumped from its normal temperature of 140°F to approximately 193°F for a period of 4 hours. Then, the temperature dropped to approximately 168°F, where it remained during full power operation. Other sensors in the immediate vicinity showed no significant change in temperature. Because 168°F exceeded the correlation matrix setpoint of 150°F for ITE-VP211, evaluation was required.

The temperature sensor is indirectly mounted on the MSIV D which carries over 4 billion Btu/hr at 550°F. It is directly mounted on an MSIV position limit switch. Because air temperature sensors throughout the drywell evidenced no significant change, it was concluded the event was local in nature. Possible causes were deemed to be:

- A small steam leak had developed at the valve.
- Insulation on the valve had vibrated loose.

The frequency of data collection for engineering evaluation was increased from weekly to daily. No significant changes in temperature occurred while the unit continued to operate. Calculations showed the electrical equipment would not be significantly affected by the 168°F temperature over a period of several years. Therefore, it was determined that no immediate action was necessary. After the unit was shut down, an inspection evidenced a small packing leak. The packings were tightened and the temperatures were closely monitored during the next period of unit operation.

Cooling Fan Failure

In March 1987, operating personnel in the main control room noticed increases in drywell temperature, drywell pressure, SRV temperature, upset range level, and shutdown range level for Unit 1. Control room indications showed the drywell cooling system was in its normal running state. However, the fan cooler entering air temperature was lower than normal for both fans.

Data were collected under the drywell temperature monitoring program. This data showed temperatures were high in the upper elevations. At lower elevations, the temperatures were low. At fan cooler B, the entering air temperature was the lowest temperature in the drywell. This indicated an operating problem with the drywell cooling system.

The immediate conclusion was that air was flowing in reverse through the cooling coil (and fan cooler). Apparently, fan B had stopped and fan A was circulating air. However, there was no specific indication of this in the control room. Further investigation revealed that the primary breaker was engaged, but read 0 amperes. Then the backup breaker was checked, and it was found tripped. This verified that the B fan was not operating.

Multiple failures of equipment had occurred as follows:

- Fan operation was indicated in the control room. This indicator was fed from a differential pressure sensor/switch across the fan. This sensor/switch was broken and gave a false indication of flow.

- The fan discharge dampers were designed with an interlock to close when the fan stopped, but they did not close. It was found that a temporary system change (TSC) had been installed because there had been a history of operating problems with the damper operators. The TSC had wired in electrical jumpers to keep the dampers open. A modification had been initiated to change the control dampers to backdraft dampers; however, it had not yet been implemented.

- The backup breaker, which did not have control room indication, had tripped. By design, it had been set at three times the amperage of the primary breaker. The failure of the primary breaker to trip was attributed to mechanical failure. Once it was cycled, it performed as expected.

The unit was shut down and subsequent investigation revealed that jacketing on one motor lead had worn through to the conductor. Contact of the bare conductor with the surrounding metal caused the breaker to trip on a ground fault. The drywell temperature monitoring program thus provided an early warning of the drywell cooling system failure and information to pinpoint the source of the problem.

LVDT Failure

In one instance involving the reactor recirculation pump flow control valve LVDTs, equipment degradation was caused by extremely localized high temperatures and for this reason was found not by the monitoring program but by operating experience. These LVDTs are used in controlling reactor heat transfer and are located above the valve bonnet. Linear voltage differential transformers were replaced during an outage, and when the unit came up, the LVDTs would remain functional for a period of several days to several months. Investigation found that the linkage connecting the LVDT to the valve had a two-dimensional motion that could not be sealed airtight, so a small local air stream of up to 400°F imparted heat to one end of the LVDT. High-temperature LVDTs were tried, but they still failed. The ultimate resolution was the installation of a 6-inch duct to spot cool each LVDT. Problems like this are difficult to discover with a temperature monitoring program. Only a detailed design review of the insulation system can detect such problems before startup.

Monitoring System Design

The evolution of the drywell temperature monitoring program provides valuable insight for the design of the coming drywell temperature monitoring system. Important factors to be considered are:

- the quantity and location of sensors;
- the use of point monitoring instead of some other method;
- the future thermal-hydraulic modeling;
- the automation of data collection and remaining life evaluations.

The installation of multiple point temperature sensors and establishment of a volumetric thermal zone have been moderately successful. Consistency of temperatures over time has been demonstrated (see Figure 7). Fundamentally, it has been demonstrated that general area temperatures are lower at lower elevations and higher at higher elevations. Hot air rises, except that local hot spots do exist close to heat sources.

For the monitoring system to do more than demonstrate the fundamentals, a mathematical model that will predict the temperature profile with local variations is needed. Temperature is a type of data and is a portion of the model. In addition to temperature, heat loads and airflows need to be modeled. A program

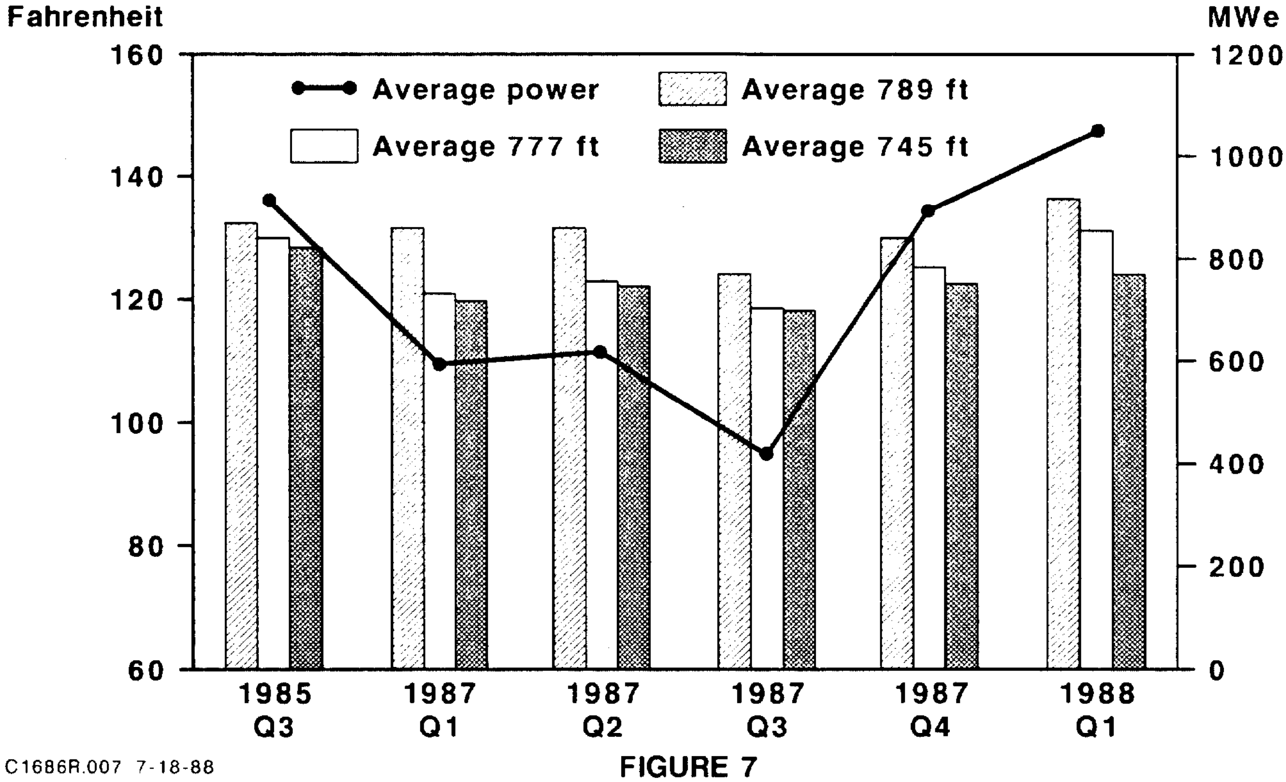


FIGURE 7
LA SALLE 1 – DRYWELL – QUARTERLY

to develop an overall thermal-hydraulic model has been initiated and will be implemented this winter.

The thermal-hydraulic model will help answer the question, "How many sensors is enough?" The quantity of sensors was more than doubled when the monitoring program was initiated. That increase was based on engineering judgment. The required quantity of sensors is probably most dependent on the temperature profile and how localized it is. However, the monitoring system does not control the profile. In contrast, the equipment and cooling system cause the temperature profile.

- Equipment has an influence in proportion with the heat it is creating. Small steam leak - small influence, but very important to the local equipment.

- At La Salle, the cooling system design is simplistic. If airflow is lost to an area, the area will get warm.

- If the monitoring point is in an area, it will experience the area temperature. If the point is on top of a piece of equipment, it will experience the equipment temperature.

This is evidenced at the MSIVs as described above in the high temperature event.

The monitoring program was recently used to demonstrate the relationship between the pipe temperature downstream of an SRV and sensor 2TE-VP205 temperature. Normally, the sensor reads approximately 125°F, and the pipe is cool (130°F - 160°F). When the temperature at 2TE-VP205 was observed to jump to over 135°F, the pipe temperature was checked and confirmed to have risen to 235°F due to a slight steam leak through the SRV. This was not an event as defined by the monitoring program because the correlation matrix temperature setpoint of 170°F was not exceeded. However, the temperature relationship demonstrates that the thermal-hydraulic concept is a good one, and that the system should make use of all the available temperature data. For example, feedwater temperature to the reactor can vary greatly while the unit is producing power. Since feedwater is a separate and significant heat load, it is planned to add this as a separate temperature point in the drywell temperature monitoring system.

The drywell temperature monitoring program has been largely manual. This has made data collection and evaluation a labor intensive task. The processing of the data to reduce it to readily interpretable information for the control room operators is needed. A colorgraphic display is an economic and prudent choice of presentation. Green temperatures would be normal, red would be higher than normal. Coloring the temperature points, such as yellow for alarm, could be used to show a temperature sensor that is experiencing a temperature inconsistent with its previous temperature history in relation to other sensors. Trend logging has proven to be very important.

Summary

As the drywell cooling modification is implemented and additional data are gathered, the temporary monitoring program will be replaced with a permanent monitoring system. It is important that the monitoring system design incorporate flexibility. High temperature events occurred and in all probability will continue to occur. Minor modifications and repairs were evaluated; the rate of degradation of equipment has been monitored and is acceptable; and the volumetric thermal data are sufficient to determine the effectiveness of the long-range modification. In summary, the drywell temperature monitoring program has been an effective method of performance monitoring.

References

1. Electric Power Research Institute, Report NP2694, "Control of Containment Air Temperature: An Industry Survey and Insulation Test."

DISCUSSION

PATEL: I have two questions. You mentioned that the design temperatures are 135°F and 150°F but you stated that the temperature reaches 300°F. Does that violate the technical specifications? Do you have a citation from NRC on this issue similar to ANO-1 plant?

BENTON: High temperature excursions are evaluated using a temperature monitoring procedure which has been audited and accepted by the NRC so it is not exactly a violation of the technical specifications. A temperature of 135°F is a bulk average for which we are taking no exception. The 160°F technical specifications on environmental qualification is, in fact, supplemented by this monitoring program. Whenever we exceed 150°F, we still report it to the NRC but we also send them an evaluation of why continued operation is acceptable based on the monitoring program.

PATEL: ANO-1 is a PWR plant and the design temperature is 120°F which was spelled out in the technical specifications. They went to 150°F and they have been cited for that.

BENTON: Again, the other utilities that have been cited have been particularly cited for not having control of their environmental qualifications. We have a very controlled program which has been accepted by the NRC.

PATEL: Concerning the qualification temperature for 300°F, does it always reach 300°F?

BENTON: The 300°F was specifically related to snubber failure. When we found the damaged equipment we came back and took corrective actions and implemented the supplemental program. We are not experiencing 300°F temperatures, typically, at this point. We had the high temperature for 15 minutes or half an hour. It fell outside of the realm of the program and all of our environmentally qualified equipment is at the SRVs or lower and some of these high temperatures are in the hot area. We monitor the hot area but it does not affect our environmental qualification program.

MOELLER: You site one reference in your paper which is an EPRI report, but there is no date. Can you tell us the year the EPRI report was issued?

BENTON: EPRI Report No. 2694, Final Report, October 1982.

ANON: Do you have the analytical program that considers buoyancy effects in modelling the dry well?

BENTON: This fall, we will be implementing what my associate described this morning as our thermal hydraulic model. My version of the model will be assigning elevations and pressures. Buoyancy will be taken into effect in our hydraulic model.

RONEY: Please explain how the 135°F average drywell temperature is determined by monitoring. Is that a volumetric average taken from the temperature sensors or is the return air to the air coolers measured?

BENTON: Per Technical Specifications, "The drywell average air temperature shall be the average temperature of the operating return air plenum upstream of the primary containment ventilation heat exchanger coil and cabinet..."

REPAIRS TO DEEP BED TYPE III ADSORBER TO CORRECT DAMAGE CAUSED BY WATER CONTAMINATION

P. E. Olson
Flakt, Inc. Bahnson Div.
Post Office Box 1128
Glen Rose, Texas 76043

Abstract

During inspections of the stations atmospheric clean-up adsorber beds water was found accumulated on the housing floor of two units. Subsequent investigation found the deluge header full of water and the drains clogged with debris. In order to return the units to an operable condition, several cells had to be cut from the housings and replaced. Modifications to the deluge valves and water supply system have been made to limit recurrence.

General Design Features

The atmospheric clean-up units employed in this system are used to filter normal ventilation exhaust air from various radiological areas prior to discharge to the outside atmosphere. 16 parallel units are used in a modular arrangement[1]. Each unit is rated for 15,000 CFM, consisting of a prefilter, adsorber bed, and a HEPA bank prior and subsequent to the adsorber. These units are completely shop fabricated. Lighting and service space were stressed in the original design, thus limiting maintenance time and reducing the associated cost and personnel exposures. Overall dimensions are 26 ft. long, 9 ft. high and 9 1/2 ft. wide, built in the late 1970's.

The adsorber beds are equipped with an automatic deluge system (ref. fig. 1) which consist of a 6" supply line, air operated butterfly valve, and 1/2" leak-off drain. The leak-off drain has a 1/16" diameter flow restricting orifice to prevent water bypass upon actuation.

The adsorber beds are 4" deep, 14 cells per unit with a residence time of .50 seconds. The adsorbent media was coconut based carbon with a potassium iodine compound impregnant.

The deluge valve is designed and shop tested for zero leakage at 200 PSI. Normal shutoff pressure at the valve is approximately 90 PSI. An air operated piston actuator is

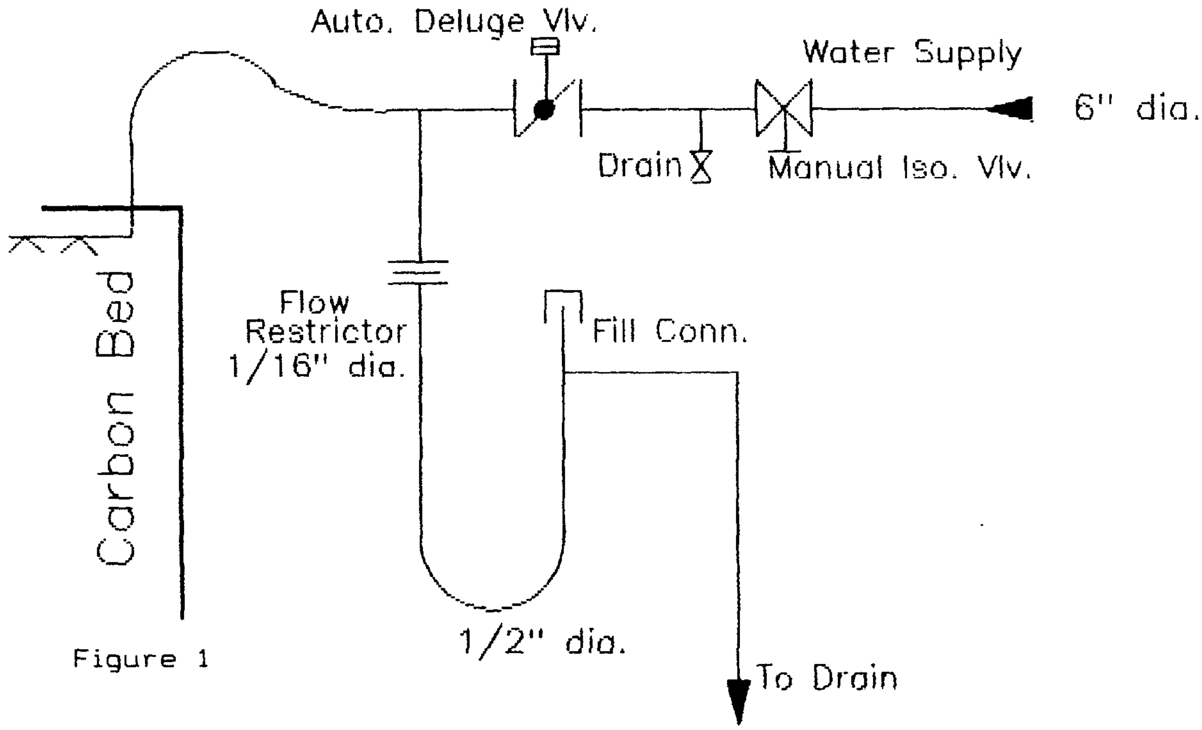


Figure 1

provided to close the valve (fail closed). Manual isolation and drain valves are provided to support surveillance testing of the automatic valve.

Carbon Wetting

Prior to installing the carbon adsorbent, the fire protection system was isolated from the unit using the manual isolation valve. After installation of the carbon the valve was left closed to allow for testing of the fire protection system (fire watch was in affect).

During inspection of the housing, water was found on the floor. Salt residue was also seen on the screens and floor area indicating that some evaporation had taken place (bath tub ring). Further investigation revealed that water had leaked by both the manual isolation valve and the deluge valve (the drain valve was closed). Water overflowed the leak-off drain, because the orifice plate was clogged with debris, and leached into the bed.

Leakage past the deluge valve was traced to the valve operator. In most cases, it would not close the valve fully (the disk would not "POP" into the seat). This was due to marginally sized actuators in addition to seal swelling and seat degradation. Bench testing of a valve fully closed with a good seat exhibited zero leakage.

There were two additional reasons contributing to the leakage. The fire protection system, which draws water from the cooling reservoir, contained high levels of sulfate reducing bacteria, initiating Microbiological Induced Corrosion (MIC) that degrated the system and damaged the seats of the upstream isolation valve. Additionally, loosened debris from the corrosion had clogged the drain orifice and damaged the resilient seats in the deluge valve. The MIC has caused the replacement of the majority of the fire protection piping and the addition of a dedicated chemically controlled water supply tank for the fire protection system.

Bed Replacement

In removing the carbon, several chunks had to be chipped out due to caking. All surfaces were rinsed and thoroughly dried.

Four 4 in. beds were found to have corroded screens, some with holes up to 1/4 in. diameter. Replacement of these cells was selected over patching due to concerns of the effects on airflow distribution and residence time. Also, qualifying a patch over suspect base material would be difficult. Each pair of cells were cut using the plasma-arc cutting technique which produces a very controlled and extremely clean cut. The beds which were not damaged by the water were covered with thin gauge sheet metal during this process to avoid inadvertent harm to the screen. The seal and support plates above and below the cell, which support the bed and prevent bypass flow, were then cut. The lower support members were removed first and small wheel carts were placed under the bed to support the cell, then the top members were cut. This allowed the cell to be wheeled out to the space between the adsorber and the downstream HEPA mounting frame. Due to space allotted in the original design (in excess of the Reg. Guide recommended three feet), removal of the cell as one piece was possible. The downstream HEPA filter bank employs the torsion bar design, on the downstream side of the frame, allowing unrestricted space between the frame and adsorber. The old cell is removed from the housing through an access hole cut in the housing wall.

The new cell, prefabricated at the shop, was moved into place in the same manner as the old one was removed. The top support members were welded into place, then the bottom. The only difference, besides cosmetic, to the original installation is the support channels (7), between adjacent screens in the air path, being welded together only at the ends where access is available. The channels now overlap one another verses being one integral piece. The seismic qualifications on the system must be adjusted to accommodate this difference. No bowing of the sceen will be evident as each cell holds only about 375 pounds of carbon.

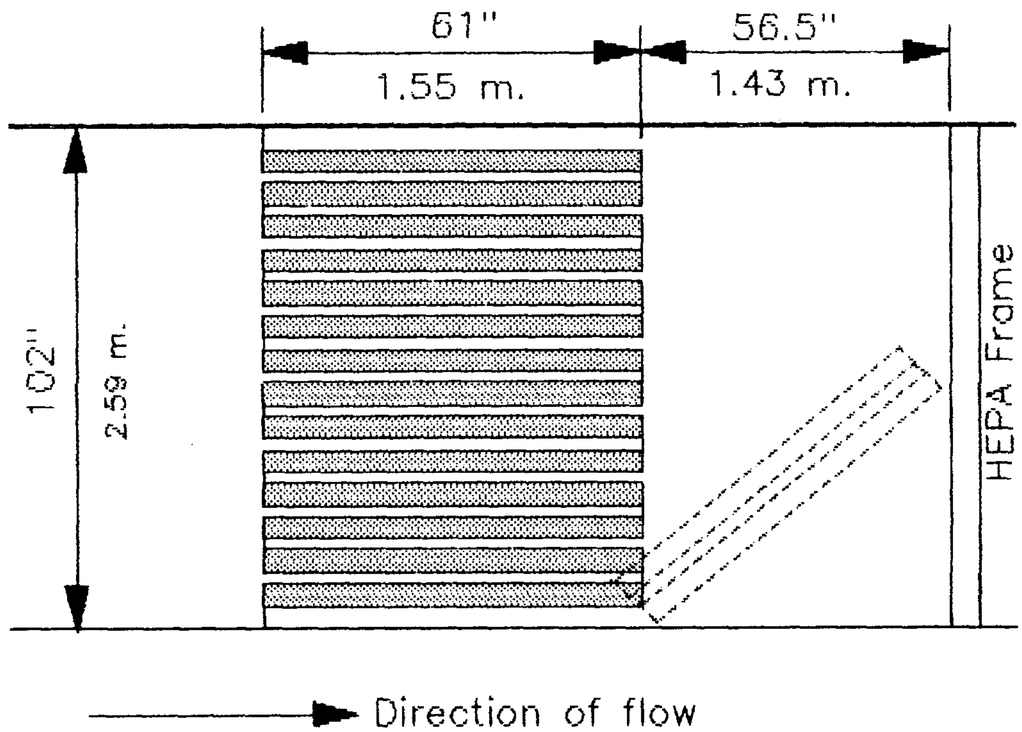


Figure 2

The housing leak test and airflow distribution test are being reperformed. A mounting frame leak test of the adsorber structure, although considered optional, is being repeated prior to carbon reinstallation due to the nature of the repairs.

Preventative Action Measures

To prevent recurrence, the following actions are being considered:

1. All deluge valve seats are being replaced.

2. Valve operators are being replaced with a type having a greater closing torque.

3. To resolve piping corrosion problems in the fire protection lines, a cleanup system has been added to maintain desired chemistry, thereby reducing deposits that may damage valve seats and clog the drain lines.

4. Insure that whenever the deluge valve is isolated for maintenance or testing, the upstream isolation valve is tagged closed and the drain valve is open.

5. Study the possibility of disconnecting the suppression system from the unit and provide an alternate method of detection and suppression in the event of a fire.

Summary

Sufficient work space around equipment cannot be overstressed, not only for normal activities like filter changeout, but the unplanned projects as explained here. In addition, interaction of systems, in this case the fire protection system and the air cleanup system, need to be more fully understood by plant engineers.

Acknowledgements

The author acknowledges the contributions and incouragement of Mr. R. E. Frankenberg, CVI Inc. and Mr. E. Nicolaysen, Long Island Lighting Company, for their assistance in the project and preparation of this paper.

References

1. Nicolaysen, Carey, and Wolak, "Standardization of Air Cleanup Systems for Nuclear Powerplants", ERDA Report CONF-760822, August 1976.

2. ANSI/ASME N509-1980, "Nuclear Power Plant Air Cleaning Units And Components".

3. USNRC Regulatory Guide 1.140, Revision 1, October 1979, "Design, Testing, and Maintenance Criteria for Normal Ventilation Exhaust System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants".

4. Burchsted, Fuller, Kahn, "Nuclear Air Cleaning Handbook", ERDA 76-21.

5. USNRC IE Information Notice 87-14, "Actuation of Fire Suppression System Causing Inoperability of Safety-Related Ventilation Equipment", March 23, 1987.

6. USNRC IE Information Notice 84-31, "Increased Stroking Time of Bettis Actuators Because of Swollen Ethylene-Propylene Rubber Seals and Seal Set", April 18, 1984.

7. ANSI/ASME N510-1980, "Testing of Nuclear Air-Cleaning Systems".

8. Graves, Hunt, Jacox, and Kovach, "Operational Maintenance Problems With Iodine Adsorbers in Nuclear Power Plant Service", DOE Report CONF-780819, August 1978.

DISCUSSION

JACOX: What impregnant was on the charcoal?

OLSON: It was 5% KI_3.

JACOX: Did you notice any pink staining from the KI_3.

OLSON: No, we did not.

ORNBERG: How long did it take you to remove and replace the adsorbers?

OLSON: It could have been done in a few days but it took us about six months to get the paper work in line. Being the unusual project it was, we had a lot of problems with our engineering function and the QC function that needed to get straightened out.

ORNBERG: But it only took a couple of days to get the work done?

OLSON: The two beds were removed in about two days.

ORNBERG: How deep was the unit?

OLSON: About 61 in.

ORNBERG: You did need the full 5 ft?

OLSON: Yes, the key was the 5 ft. If it was not for that, we would have had to cut the entire end of the housing off.

ORNBERG: Just as a reminder, I gave a paper at the last Air Cleaning Conference about changes to ANSI N-509 in the fire protection area. At that time, I said N-509 would be out at the beginning of 1988. I did not foresee three rounds of ballots in the ASME Committee on Nuclear Air and Gas Treatment. But it has passed through that committee and is now with the Board of Nuclear Codes and Standards. The new guidance states that it is acceptable to disconnect the fire protection systems, i.e., to eliminate a hard piped fire protection system. It permits one to have the nozzles inside and double valving outside so that a fire hose can be connected as needed. There were other discussions at the last Air Cleaning Conference regarding alternative types of fire protection, including no protection with isolation. There have been changes in this area and many are being brought about because of experiences such as you described.

OLSON: Comment acknowledged.

PORCO: How do you account for only four of the sixteen beds being damaged?

OLSON: The beds damaged were the ones on the side of the housing nearest the deluge valve. As the water was not under pressure, we believe not enough water entered the sprinkler pipe to migrate all the way across the unit headers.

PORCO: How did you inspect the remaining beds?

OLSON: We used some mirrors with extensions to go down the beds and look for any signs of water. For housings where we saw no water, we opened up each of the drain lines just downstream of deluge valve to see if there was any standing water.

LECKIE: Do you know how long the leakage took place to do that much damage to the stainless steel screens? Was it several months, a year?

OLSON: It was not a year. We estimated it to be 3-4 weeks.

UPGRADE OF THE RADIOACTIVE AIR EMISSION SYSTEMS AT OAK RIDGE NATIONAL LABORATORY*

E. L. Youngblood, S. P. du Mont, and R. E. Helms
Martin Marietta Energy Systems
Oak Ridge, Tennessee

Abstract

A program is under way to upgrade the radioactive air emission systems at Oak Ridge National Laboratory (ORNL) to ensure long-term system reliability and compliance with environmental regulations. The primary sources of radioactive air emissions are cell ventilation and process off-gas from reactor operations and isotope production, analytical facilities, and laboratories used for research and development. A major portion of the radioactive air emissions is discharged through seven separate ventilation stacks, several of which have been in operation for over 25 years. Improvements that are being addressed by the program include: (a) replacement of deteriorated ventilation ducts, filter systems, and fans and motors; (b) upgrade of sampling and monitoring systems to provide isokinetic sampling and improved analysis and data management; and (c) reduction in emissions and potential radiation exposure associated with the air emission systems.

The program includes both studies and capital projects for facility upgrade. To ensure that all emission sources have been identified and evaluated, a comprehensive stack-and-vent survey was performed and recorded in a computer data base. Studies have been performed to determine the cost/benefit of further reduction in tritium emissions, to evaluate the methods of repair of the underground concrete ventilation ducts, and to evaluate the condition of fans and motors by vibrational analysis. Thus far, an excess of $10 million in upgrades have been added to the existing radioactive air-handling systems and another $6 million in improvements are projected over the next 3 years. Example projects to upgrade a stack ventilation system and a stack monitoring system are described. Studies for determining future upgrade requirements are discussed.

I. Introduction

A program is under way to upgrade the radioactive air emission systems at Oak Ridge National Laboratory (ORNL) to ensure long-term reliability and compliance with environmental regulations. The primary sources of radioactive air emissions at ORNL are cell ventilation air and process off-gas from reactor operations, isotope production, laboratories used for research and development, and analytical facilities. A major portion of the air is discharged through 7 vent systems, most of which have been in operation for over 25 years.

*Work performed under DOE Contract No. DE-AC05-84OR21400

Control of radioactive air emissions at ORNL facilities is provided in accordance with the Clean Air Act and U.S. Department of Energy (DOE) Orders and objectives to keep emissions "As Low As Reasonably Achievable" (ALARA). The Clean Air Act authorizes the establishment of National Emission Standards for Hazardous Air Pollutants (NESHAP). Radionuclides are regulated under these standards, which limit radionuclide emission from DOE facilities into the air to a dose equivalent rate of 25 mrem/year to the whole body or a dose equivalent of 75 mrem/year to the critical organ of any member of the public. Radioactive gas emissions from ORNL facilities are in compliance with existing regulations. Calculated exposures from releases in 1986 indicated a maximum whole body dose commitment of 0.5 mrem (about 2% of NESHAP standards). The radionuclides released in the largest curie quantities were tritium and noble gases (xenon-133 and krypton-85). Since the radioactive air emissions at ORNL facilities are in compliance with existing regulations, the primary objective of the upgrade program has been to ensure long-term reliable operation of the ventilation systems and to identify and improve systems to reduce emissions.

The program includes both studies and capital projects for system upgrade. Thus far, an excess of $10 million in upgrades have been completed for existing radioactive air-handling systems and an additional $6 million in improvements are projected over the next 3 years. Examples of projects to upgrade stack ventilation systems and stack monitoring systems and studies for determining future upgrade follow.

II. Description of Radioactive Air Emission Systems

Essentially all radioactive air streams at ORNL (including ventilation air and process off-gas) are filtered through roughing filters and two banks of high-efficiency particulate air (HEPA) filters before being discharged to stacks ranging in height from 14 to 250 feet. Where conditions dictate (particularly in the process off-gas systems), charcoal absorbers or chemical scrubbers are used to remove reactive gases, such as iodine and acidic vapors. Noble gases are diluted with cell ventilation air and discharged to the stack. Because of the small quantities involved, collection and storage of these gases is not considered practical. The procedures and equipment used in the tritium processing facilities are designed to reduce the release of tritium. There is no additional tritium removal equipment in the stack discharge systems.

The basic equipment used in the ventilation systems that discharge to the major stacks includes filters, fans, and the ducts for transporting the air. Typically, filters are located in concrete pits below-grade with the top surface of the pit exposed. Figure 1 is a cross section view of the filter system that is used for building ventilation and the hot off-gas system for the High Flux Isotope Reactor. In addition to the two HEPA filters, silver plated copper filters and charcoal absorbers are used for iodine removal. In several locations, underground ventilation ducts, up to 54 in. in diameter and constructed of reinforced concrete, are used to convey the ventilation air from several facilities to a single stack. Above-ground stainless steel ducts are used near the

ORNL-LR-DWG 77798R5

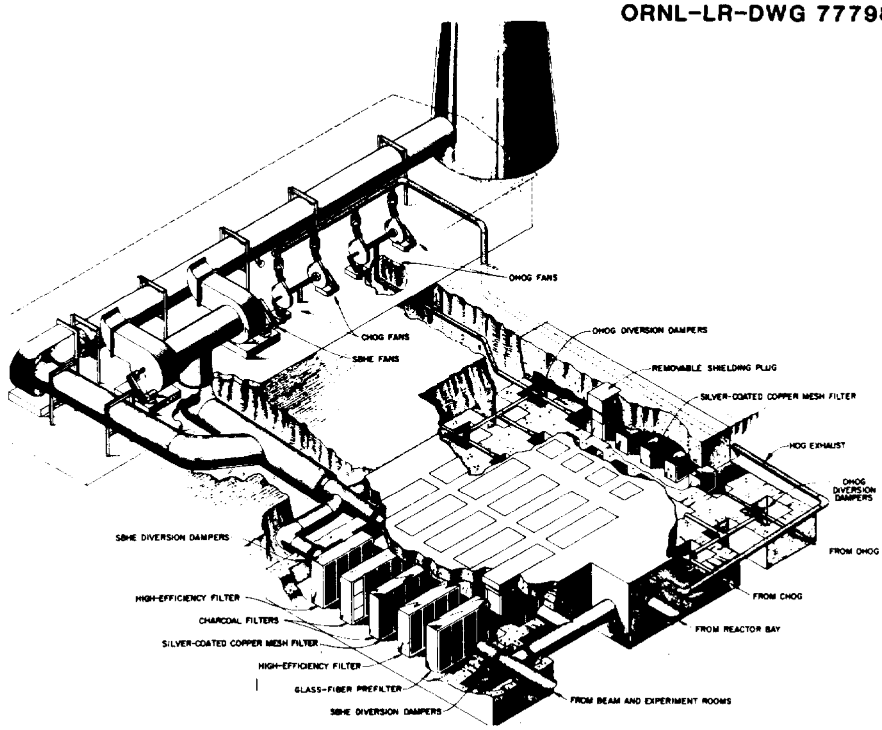


FIGURE 1
FILTER SYSTEM FOR HIGH FLUX ISOTOPE REACTOR

fans and stacks. Figure 2 is a schematic of one of the main ventilation systems that serves facilities for isotope production, reactor operation, waste processing and storage facilities, and radiochemical laboratories. Typically, treatment and filtration of the air is done locally before entering the ventilation ducts. Standby steam turbine-driven fans or electrical fans with emergency electrical generators are used to ensure continuous operation of the ventilation exhaust system. Air emissions for each of the major stacks are continuously monitored and sampled to provide data for compliance with air emission standards and to indicate abnormal emission rates. The upgrade of the air emission and monitoring systems and a description of studies that have been done are discussed.

III. Upgrade of Air Emission Systems

The primary reason that upgrade has been necessary is because of deterioration during the long period of service (over 25 years for most systems). Upgrades are being done to correct deficiencies caused by deterioration of carbon steel ducts, groundwater intrusion into underground ventilation ducts and filter pits, deterioration of filter holder frames and sealing surfaces, worn and obsolete fans, motors, and emergency generators and also to provide additional HEPA filters in series for backup of existing filters. Upgrade of existing ventilation systems is greatly complicated by the presence of radioactive contamination and the need for continuous ventilation flow and the requirement to

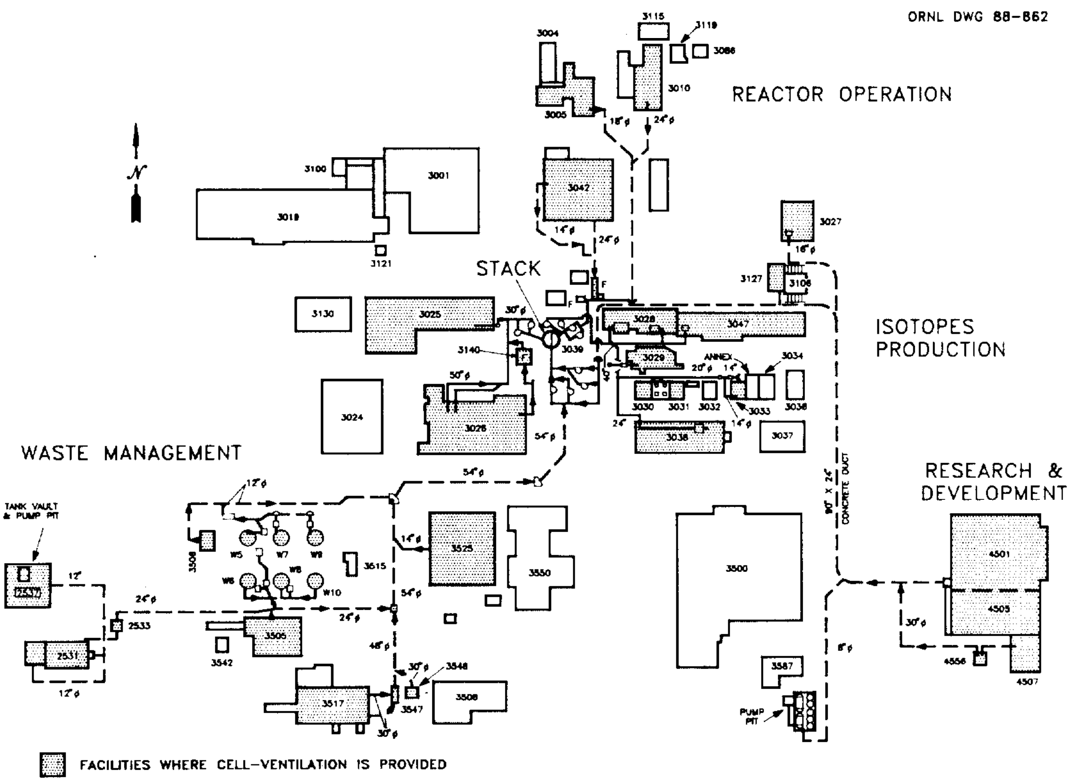


FIGURE 2
SCHEMATIC OF UNDERGROUND VENTILATION SYSTEM

maintain negative pressure on the facilities served for contamination control. Table 1 is a list of the major stacks and the upgrades that have been completed or are planned.

Typical results of a major upgrade of a stack air emission exhaust system at ORNL are shown in the before and after photographs in Figs. 3 and 4. This work was initiated in 1980 and completed in 1986, at a cost of about $8 million. The deteriorating carbon steel ventilation ducts were replaced with stainless steel ducts designed to last for 30 years. Most of the fans were replaced or refurbished. Underground ducts in one area were replaced with a stainless steel, locally filtered overhead system. One of the most challenging problems associated with the project was to maintain continuous ventilation to facilities at all times, except for very brief periods during change over. This was accomplished through the use of a temporary system. The work other than that done in a contaminated environment was done by an outside fixed-fee contractor. The ducts and equipment were contaminated with radioisotopes (primarily cesium, strontium, and cobalt) and had radiation levels up to 2 rad/h. ORNL regulations required that the radiation level be reduced by decontamination and shielding to less than approximately 0.5 mrem/h before outside contractor personnel could be used. Presently, most contamination-related work is done through cost-plus-award-fee contracts. Typically, long runs of contaminated duct are cut into 8- to 10- ft sections,

Table 1. Status of upgrade of major ventilation systems at Oak Ridge National Laboratory.

STACK	FACILITIES SERVED	DUCTWORK	FANS & MOTORS	FILTERS	EMERGENCY GENERATOR	STACK MONITORING
A.	Isotope Proc. Waste Handling R&D	I	C	I	I	C
B.	Tritium Target Fabrication				I	C
C.	Reactor Processing Plant		I	I		C
D.	Radiochemical Processing Plant	C	C	I	C	I
E.	High-Radiation Level Analytical Lab.					I
F.	Molten Salt Reactor (Inactive)		I			I
G.	Electron Accelerator					I

C - completed I - in progress or planned

capped, wrapped in plastic, and transported to a local burial ground for disposal. Sometimes low-level waste is compacted before disposal.

Demolition of contaminated ductwork is always conducted so that ventilation is maintained on the duct during cutting to ensure that any particulates are swept toward the filters and stacks and, thus, do not contaminate the workers. Cutting may be done by hot rodding (stainless steel), oxyacetylene torch (carbon steel), and reciprocating saw (where torching is a fire hazard as for the filter houses). Environmental protection officers may require that substantial containment shelters be constructed around the ductwork while it is being demolished. Capping of the cut ends must be

ORNL PHOTO 0531-78

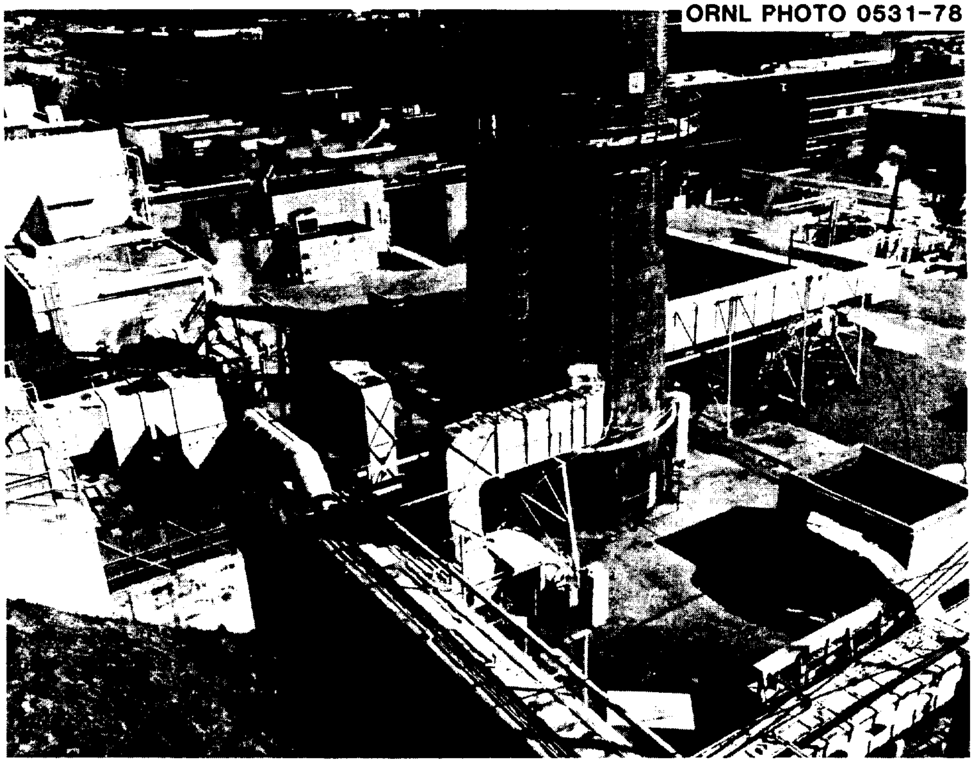


FIGURE 3
TYPICAL VENTILATION SYSTEM BEFORE UPGRADE

ORNL PHOTO 4552-86

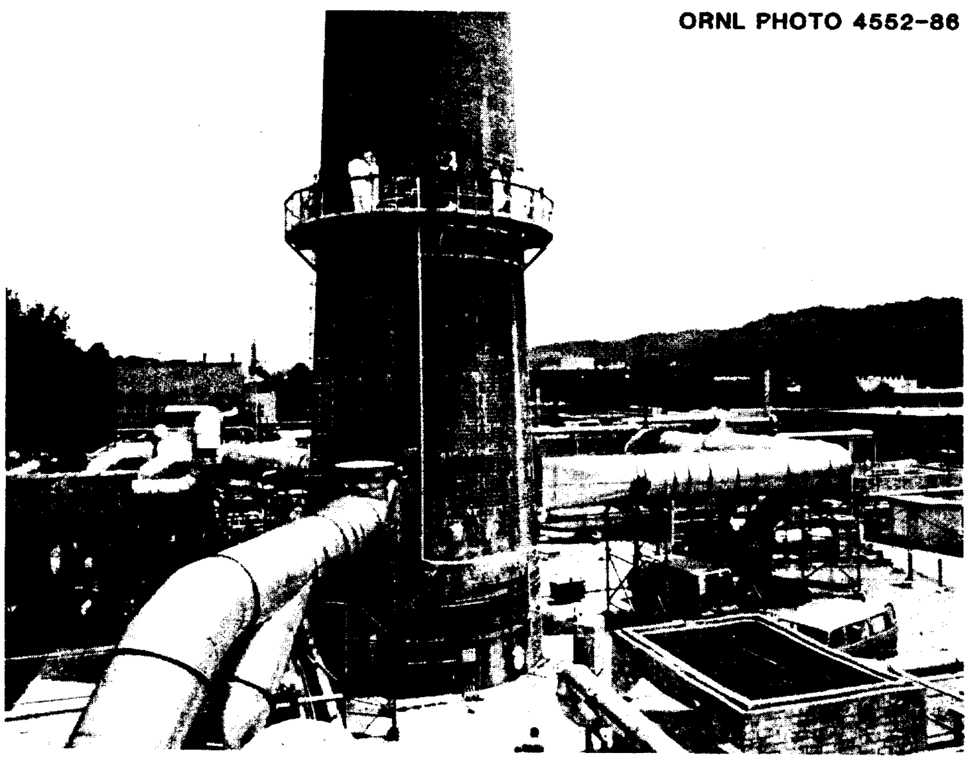


FIGURE 4
VENTILATION SYSTEM AFTER UPGRADE

conducted with great care (sheet metal caps, sheet metal screws, double or triple layers of tape) to prevent spread of contamination. Corroded ductwork may be so flimsy that it must be transported in wooden boxes to avoid breaching or breakage. All demolition wastes are handled according to a required document, the Project Waste Management Plan, reviewed, and approved by burial ground and waste management officials at ORNL. Shipment of wastes requires documentation log-in datasheets and radiation control documents. Asbestos and hazardous materials require additional documentation. Wastes at ORNL are divided into 18 categories with 10 different disposal sites. Radioactive ductwork has seldom been found mixed with asbestos or other hazardous materials.

In addition to the upgrade described previously, work is under way to upgrade this system's filter pits that have sealing problems and individual filters that do not meet the DOP efficiency requirements of 99.95%, although the total system meets the requirements. The problem is primarily due to corrosion of the carbon steel filter frames. High radiation levels in the filter pits (up to 100 rad/h) make it impractical to repair the frames in some cases and replacement is necessary. Stainless steel frames are used in all upgraded systems.

Another problem encountered in the upgrade of the system is dispersion of DOP for filter testing in those that must be located in close proximity. Limited space and work in contaminated areas often makes it impractical to separate filters by distances of 10 duct diameters or greater to achieve good mixing. Commercial filter manufacturers now appear to have adequate DOP dispersion systems for this application.

Surface and rain water inleakage has been a significant problem in some of the filter pits. Enclosures are being installed to eliminate rain water inleakage, and in some areas, replacement and decommissioning appears to be the only practical solution to groundwater inleakage.

IV. Upgrade of Monitoring and Sampling Systems

The monitoring and sampling systems for all of the major stacks are being upgraded to provide isokinetic-type sampling, to replace instruments of obsolete technology, and to improve data collection and analysis. Thus far, the monitoring and sampling systems for three of the main stacks have been upgraded, and upgrade of four other stacks is in progress. Typical old and new monitoring and sampling systems in which the samples are taken at the 50-ft level of an 11-ft, 3-in. (inside diameter) stack are shown in Figs. 5 and 6. In the old system, single sample points were used for the monitoring and sampling systems. In the new system, multiple sampling points are used in accordance with ANSI N13.1-1969. Although the stack flow is relatively stable, multiple thermal-mass flow elements are used to provide the capability of tracking if variations in flow should occur.

Standardized monitoring instrument carts are being used on all systems. Standardization has been beneficial both in data analysis and in providing spare parts and training for maintenance; however,

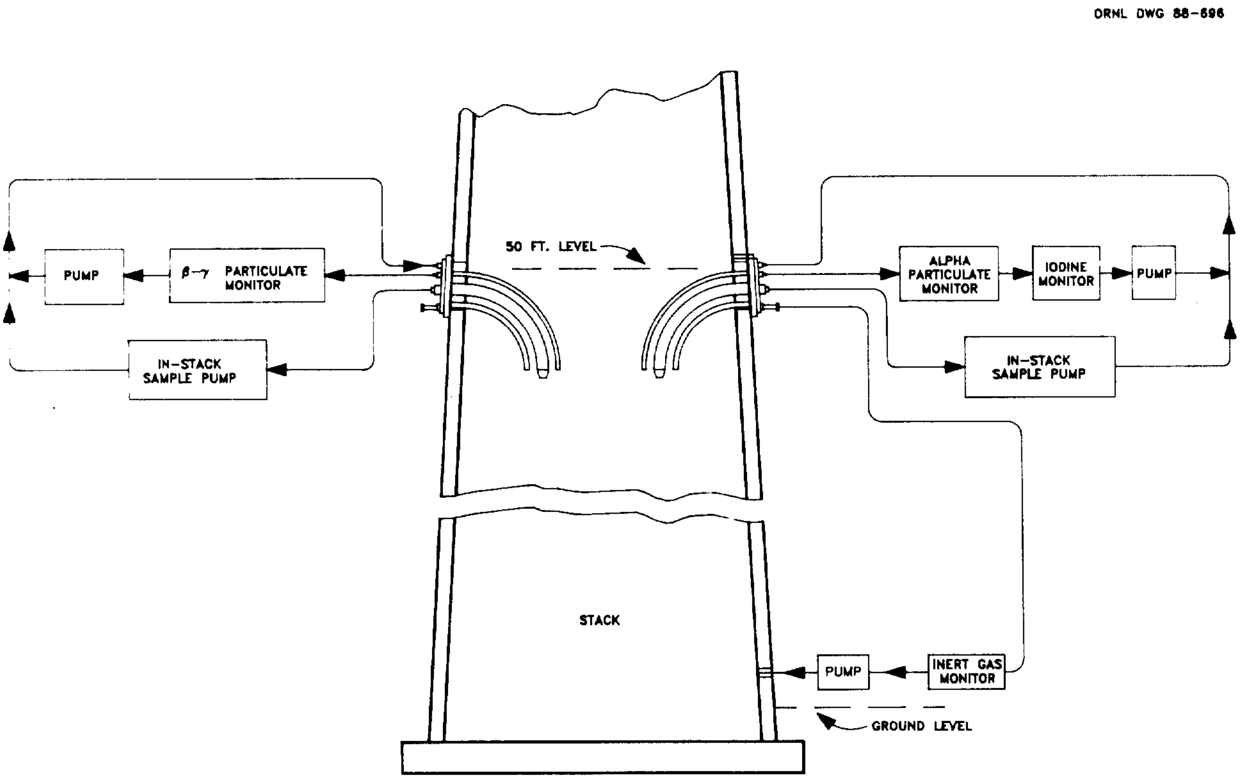


FIGURE 5
STACK MONITORING SYSTEM BEFORE UPGRADE

it will not be allowed to prevent the use of the best available technology in future projects. The carts contain instrumentation for measuring alpha and beta particulates, iodine, noble gas, and tritium. The particulate channel consists of a filter, shielded detector (scintillator and photomultiplier tube) for beta and alpha activity detection, and pulse-processing electronics. The iodine monitor is located downstream from the particulate instrument and contains a charcoal filter to remove iodine and let the noble gases pass through. A gamma scintillator optically coupled to a photomultiplier tube is used to detect the 364 keV gamma emitted by iodine-131 and discriminate against radiation from noble gases. The noble gas monitor contains a beta scintillation detector and a sensitive volume of air enclosed in a shield. The monitor is designed primarily to detect beta radiation from krypton-85 and xenon-133. Each of the monitors is equipped with a solenoid-operated source to test and verify the unit. The tritium monitor consists of dual lead-lined ionization chambers with an integral electrometer coupled to the electronic circuit. One of the ionization chambers is used to cancel the effects of external radiation on the measuring ionization chamber.

ORNL DWG 88-663

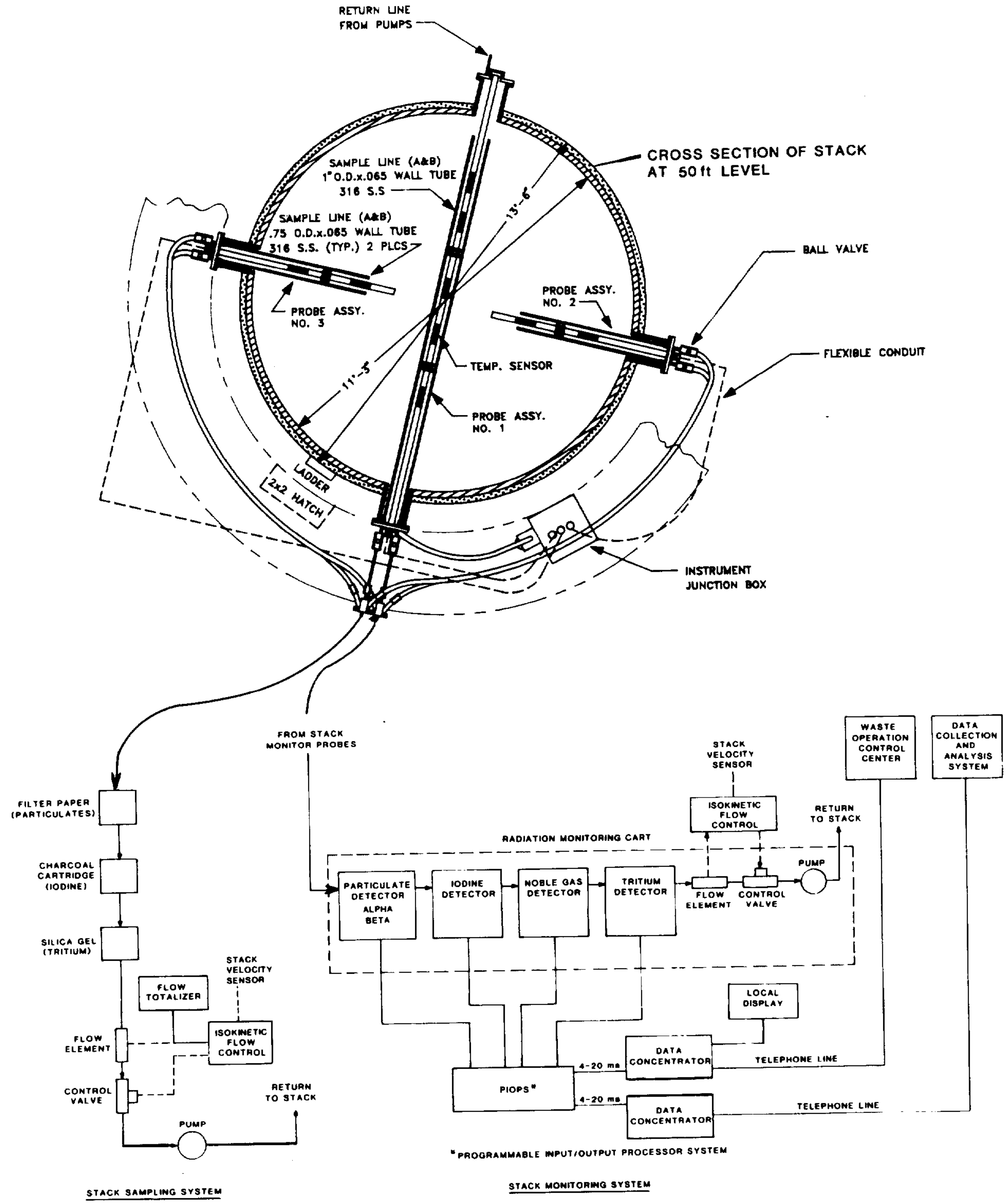


FIGURE 6
STACK MONITORING SYSTEM AFTER UPGRADE

Signals from the monitoring system are sent to a data concentrator, which provides real-time data and past data (up to 24 hours) to a local display. In addition, the signal is transmitted by telephone lines to the Waste Operations Control Center (WOCC), which is manned continuously, and the signals are monitored for abnormal conditions. The signals are also transmitted to the Data Collection and Analysis System, through which the data are processed and analyzed. The addition of the data collection system and monitoring of the signals by the WOCC has been a major improvement in the operation of the system.

The stack sampling system has also been upgraded to provide isokinetic sampling of the gases. As shown in Figure 6, a separate set of sample nozzles is used. In the sampling system, air samples are continuously passed through filter paper, charcoal filter, and silica gel, which are all periodically removed for laboratory analysis for alpha and beta particulates, iodine, and tritium. The sampling system is primarily used to determine total radioactive emission discharges from the stacks.

Checkout of systems for three stacks has been completed, and about six months of operating experience has been obtained. In general, the upgraded systems have performed satisfactorily.

V. Studies and Evaluations

In support of the upgrade program, studies and evaluations of ventilation emission systems were made to determine the condition of equipment and to determine if additional pollution control equipment is needed. Initially, a stack-and-vent survey was conducted to identify all air emission sources for location and the type of pollutants emitted. Approximately 2,000 air emission sources were identified and recorded in a computer data base. In addition to being used as a basis for state permit applications required by the Clean Air Act, an engineering evaluation was made to assess the need for further system upgrade.

Vibrational analysis was used to determine the condition of the fans and motors associated with the main stacks. Vibrational data in the range of 0 to 2,000 Hertz were gathered using an electronic accelerometer, which was moved between locations on each fan and its driver (electric motor or steam turbine). Data were collected using a tape recorder, and information from the tapes was processed through a digital signal analyzer to produce a vibrational signature for each bearing. These were analyzed to evaluate the condition of the fans. Of the 38 fans analyzed, approximately 6 were determined to need replacement. The data base established by the vibrational measurements is being used to set up a routine surveillance and preventive maintenance program for the fans.

Inspection of the underground reinforced-concrete ventilation ducts is being done by direct entry when feasible and with remote video cameras for smaller ducts and where radioactive contamination levels are excessive for direct entry. The inspections made to date have revealed groundwater inleakage and areas of deterioration of the concrete as shown in Figure 7. Repair or replacement of the ducts is very difficult because of the presence of radioactive

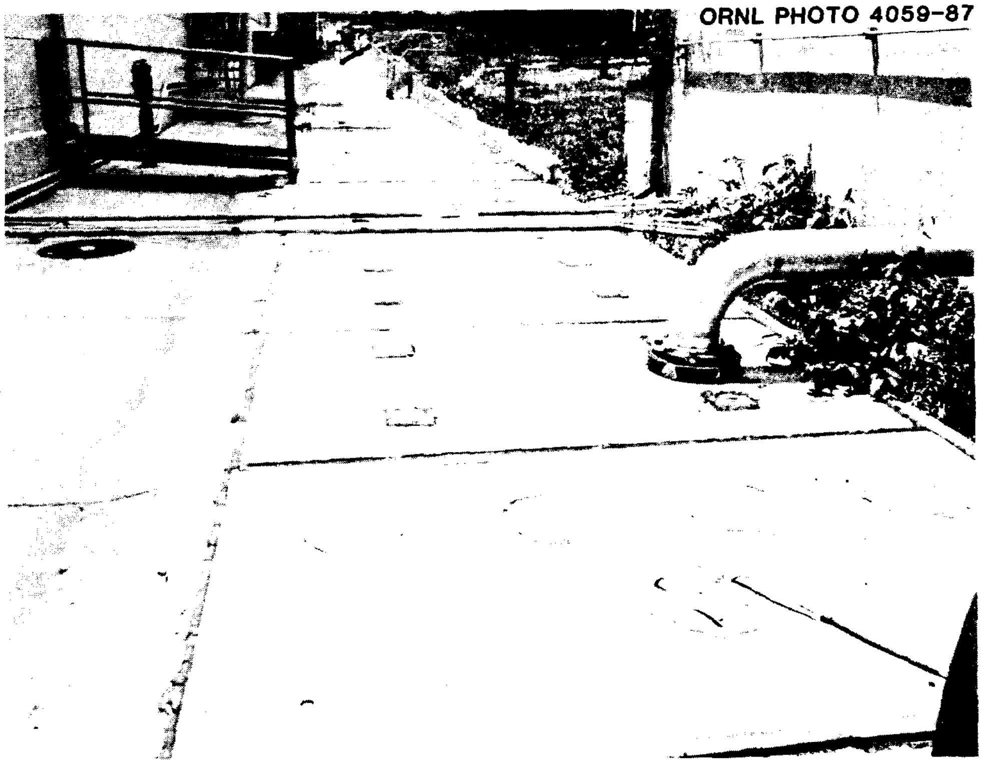


FIGURE 7
DETERIORATION OF CONCRETE VENTILATION DUCT

contamination and the requirement to provide continuous ventilation to the facilities served. Alternative methods of repairing the ducts are being evaluated by an outside subcontractor.

Although the radioactive air emissions from ORNL facilities are very low (approximately 2% of NESHAP), cost/benefit studies were made to determine the feasibility of further reduction in emissions. The study concentrated on tritium release because this is the radionuclide that contributes most (approximately 90%) to the off-site dose commitment. The studies indicated that further reductions of tritium are possible by the use of improved vacuum pumps and the addition of new tritium removal equipment to the main tritium emission streams.

VI. Summary and Conclusions

The major ventilation systems, through which radioactive air emissions are discharged at ORNL, are being upgraded. Since the air emissions are generally in compliance with existing environmental regulations, the primary purpose of the upgrade is to repair the deterioration that has occurred over a long period of operation (over 25 years) and to modernize equipment used in the ventilation and stack monitoring and data collection systems. Studies and evaluations were made to (1) identify and characterize all emission sources, (2) determine the condition of fans and motors by vibrational analysis, (3) assess methods for repair of underground ventilation ducts to eliminate water inleakage, and (4) further reduce radioactive air emissions (primarily tritium). As a result, radioactively contaminated carbon steel ductwork has been replaced with stainless steel ducts at two of the major stacks, and ventilation fans and motors have been replaced or refurbished in two systems. Projects are under way to correct problems with groundwater inleakage into underground filter pits and ventilation ducts. The stack monitoring and sampling systems for three major stacks have been upgraded to provide near-isokinetic sampling, to replace instruments of obsolete technology, and to improve data collection and analysis. It is significant to note that control of contamination and services to facilities served has been successfully maintained during the upgrade program.

DISCUSSION

PARTHASARATHY: There was a paper this morning that advocated using a single nozzle for stack monitoring. I note in your presentation that you replaced a single nozzle with a multiple nozzle sampling system. Were velocity profiles made at the 50 foot level to see if it was the ideal location for your sampling nozzles?

YOUNGBLOOD: There were no more suitable locations although the one selected may not have been ideal. When you can be sure that the concentration is uniform across the stack, one nozzle is fine, I think, but if you are not sure you have uniformity, you need more than one. Since we could not assure uniform mixing in the stack a multi-nozzle sampling system was used to provide a representative sample over the entire stack cross section in accordance with ANSI N13.1-1969.

PARTHASARATHY: The 50 foot level did not appear to be too far away from the entry to the stack. Did you consider going higher up into the stack to get a better distribution?

YOUNGBLOOD: The 50 foot level of the stack was selected for the sampling location because of the availability of ports and a platform at that location. Several velocity profile measurements were made. They indicated that the velocity profile was relatively flat and suitable for isokinetic sampling at that location.